Co-Cognition, Neural Ensembles and Self-Organization[Π]

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Abstract

In nature, organisms and species coexist in an ecosystem, where each species has its own place or *niche* in the system. The environment contains a limited number and amount of resources, and the various species must compete for access to those resources, where successive adaptations in one group put pressure on another group to catch up (e.g., the coupled phenomena of speed in the cheetah and evasive agility in the gazelle). Through these interactions, species grow and change, each influencing the others evolutionary development. This process of bi-adaptive relationship (in some cases can also assume a form of cooperation and mutualism) or reciprocal adaptation is know as *co-evolution*. Co-evolution (i.e. the evolution of two or more competing populations with coupled fitness), has several interesting features that may potentially enhance the adaptive power of artificial evolution, or as stressed by the present talk, of other types of bio-inspired learning systems. In particular, competing populations may reciprocally drive one another to increasing levels of complexity by producing an evolutionary "arms race", where each group may become bigger, faster, more lethal, more intelligent, etc. The expected increased success and efficiency of co-evolutionary search algorithms, are also due to other reasons typically cited as the possibility of an adaptive and measurable *performance* gradient (i.e. the gain in efficiency of the evaluation of evolving solutions) which could otherwise be hard to engineer, focusing adaptation on any relevant target, i.e. on those aspects of a task that have not yet been optimised, the possible automatic adjustment of the selection gradient which is imposed on the evolving solutions, and finally on the above cited potential open-ended nature of these systems. Due to these reasons, the idea of reciprocal and iterated adaptation has become increasingly popular in Evolutionary Algorithms research as in related areas such as Swarm Intelligence, providing general-purpose approaches to the problem of machine learning, either between a learner (e.g., single population) and its environment (i.e. based on competitions among individuals in the population) or between learning species (two populations evolving), where the fitness of individuals is based on their behaviour in the context of the individuals of the other population. This latter type of co-evolutionary search is often described as "host-parasite", or "predator-prey" co-evolution.

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Examples and applications of co-evolutionary learning include the pioneering work by *Hillis* in 1990 on sorting networks, game learning, predator and prey dynamics along with pursuit/evasion tactics, spatial distribution problems, spatially embedded systems where more successful results could be achieved in contrast to standard spatial embedded evolutionary models, the use of techniques such as fitness sharing to produce and maintain diverse populations, techniques such as lifetime fitness evaluation to retain good solutions in the populations, or collective evolutionary and swarm robotics. Finally the research field has several applications on evolving cellular rules for uniform and non-uniform Cellular Automata, namely on using the density classification task (*Majority function*) on this type of machines as a test-bed set for understanding the behaviour of co-evolving systems.

None of these works however, tried to implement or study the co-evolving phenomena at brain-level. What are, for instance, the dynamics of several independent and competing synaptic clusters receiving feedbacks from each other? Can we implant the above cited advantages into the design of Neural Networks or in sparsely distributed neural ensembles? In order to answer these questions and to fulfil it, we start by adopt a recent model of self-organizing and bio-inspired Artificial Neural Network (ANN), operating at a highly adaptive, probably critical state, and implement a coupled pair system of NNs that learn by symmetrical feedback of one network into the other. As in past works, the predator/prey case was used as a test set to understand the behaviour of such system. On the other hand, the study of ANNs is a huge and diverse field, but perhaps one of its most interesting applications is in modelling the biological system that inspired these algorithms in the first place: the brain. Following the suggestion by *Bak* and others that the brain may operate at a critical level, a number of particularly elegant ANN models have been put forward perhaps the most appealing and simple being that created by *Bak* and colleagues: recently dubbed the "*minibrain*", it uses extreme "winner-takes-all" dynamics similar to those of recent evolutionary models (also as SOC - *Self-Organized Criticality* systems) and solely negative feedback to create a fast and highly adaptive learning system. Once an output has been produced (the architecture is completely irrelevant), the authors envision a hardwired "*Darwinian* good selector" determined by biological evolution that evaluates whether the output produced is a satisfactory response to the input. If it is, no further action is taken. If not, however, a negative feedback is sent to the system (similar to *evaporation* in ant colony computational approaches), and all the synaptic connections responsible are "punished" by having their strength decreased by a random amount (biologically, one might imagine that synaptic activity leaves behind a chemical trace tagging the synapse as "used", with the feedback signal being the release of some hormones; a related and similar concept used in *Swarm Intelligence* and Self-Organization). What strikes from this SOC neural system are power-law signatures ubiquitous in nature as those found by *Bak* himself on *sandpile* dynamics. Unlike most traditional methods (e.g. *Hebbian* learning) and unlike the traditional conception of neuronal dynamics only negative feedback is used; there is no reward at all to synapses for making a "good" decision. Authors are thinking of the mechanism as *Synaptic Darwinism* and suggested within this context an valid alternative model to *Hebbian* learning (*Parity* class problems and their lower dimensional sub-cases, as XOR, are among the successful cases learned).

In here we carefully extend the above cited synaptic dynamics into co-evolutionary scenarios, proving that neurons as genes can co-evolve too. Moreover and equally important, the present work points out that co-evolving frameworks of reciprocal adaptation and competitive embedded learning like those used by *Hillis* in the evolutionary computation realm, could also be exploited in neural network design, as in those with more biologically plausible learning mechanisms. When properly embedded, the behaviour of these organisms is highly stimulating. First, the competitive environment can increase learning. In fact and as reported by other authors, if the prey is very efficient, the probability that an individual with a randomly generated genotype (synaptic weights in our case) may be able to catch it is very low. As a consequence (and within standard co-evolution) all individuals will be scored with the same value and the selective process cannot operate. In the present case, the NN learns very little. On the contrary, interesting and emergent behaviours appear when a predator interacts with a variety of preys. Moreover, this factor also increases the possibility of real generalization, a theme that it is still badly studied on this type of networks. Second, and with some connexion with the first point, in very stable environments where selective pressures are relatively fixed and expected, behaviours are stereotyped and little variable. On the other hand, in areas of great environmental instability, answers are multiple and diverse, and the organisms exhibit a vast behavioural array, that allows them to survive and evolve in a ever-changing habitat. This is in line with the 1942 speciation theory of *Ernst Mayr*. Finally and as emblematic within co-evolving systems, in some instances *Red Queen* dynamics can also occur. The phenomenon is referred to the *Red Queen hypothesis* of *van Alen*, where species in co-evolved contexts have to keep adapting just to maintain the status quo. Among these and other observations, we will in particular, try to understand in what conditions co-evolution can lead to "arms races" in which two or more independent synaptic clusters (designed as different self-organized synthetic and neural organisms) reciprocally drive one another to increasing levels of complexity.

Albeit being the present *Host-Parasite* approach the first attempting algorithmic structure to link and unify three major areas in complex systems (*evolution*, *self-organization* and *cognition*), a unique common concept seems to emerge, interlocking all them: *chemotaxis* and *stigmergy*, pointing us out a possible and feasible roadmap for future robust adaptive computational systems, while highlighting further clues on our nature's nature. Proceeding further, several tests were conducted in hard bounded rationality environments (e.g. the *Iterated Prisoners Dilemma*) where memory and information is incomplete and – nevertheless – long term strategic decisions should be taken. Since the earlier days of the famous *Axelrod* first experiment, *TIT-for-TAT*, was finally beaten with the present framework, after 20 years of several and heterogeneous worldwide attempts. "*Good news*" is that the emerged *host-parasite* strategy is as gentle as *TIT-for-TAT*. "*Bad news or maybe not*" is that she tries to acknowledge is partners later on time, thus trying to overcome greedy-viral agents on the overall environment.

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Vitorino Ramos

Research areas:
Vitorino Ramos main research interests are in the fields of *Artificial Life and Intelligence*, *Bio-Inspired Computation*, *Collective Intelligence and Complex Systems*, playing special attention to the role of E*volution*, *Self-Organization* and emergent *Cognitive Learning* on computational intelligence aspects. Areas of application include Pattern Recognition, Image Analysis and Processing, Data Mining, Dynamic and Combinatorial Optimization and Control, Classification, Information retrieval, Neural and Evolutionary Computation, Ant Colony Optimization as other related Metaheuristics, Forecasting, Learning and Adaptive systems, Generative Art, Co-evolution and Decision.
Biography:
On these areas, he has published over than 70 papers in International Conferences and Journals, participated in 10 National and European research projects (being the main researcher in 2 of them), co-organized several special sessions in International Conferences, and co-edited 2 books at Springer-Verlag (Studies in Computational Intelligence). He also created and chairs since 2004 the Swarm Intelligence and Patterns (SIP) series of Workshops held since then at different International events. He has been invited to the program committee of several known Int. Conferences on his research areas such as CEC (Congress of Evolutionary Computation), PPSN (Parallel Problem Solving from Nature), aLIFE (Simulation and Synthesis of Living Systems), NiSIS (Nature Inspired Smart Information Systems), ECAL (European Conf. on Artificial Life), IEEE Swarm Intelligence Symposium, MA4CS (Multi-Agents for Modeling Complex Systems), AISB (Adaptation in Artificial and Biological Systems), Complex Systems Conf., ICANNGA (Adaptive and Natural Computing Algorithms), SAC (ACM Symposium on Applied Computing), CIARP (Ibero-American Congress on Pattern Recognition), ACVIS (Advanced Concepts for Intelligent Vision Systems) and many others. He has also been a reviewer on these events as well as for several dedicated Journals, Book Chapters and worldwide PhD thesis.
Some of his invited lectures include Universidad del País Vasco (Bilbao, Spain), Univ. of São Paulo (Brazil), Complexity in Social Sciences Summer School (COSI European Research Network, Andaluzia, Spain), Univ. of Lyon (France) and Univ. of Birmigham (UK), among many others.
In 2002, he was invited by the European Commission (among 30 scientists), to discuss the nature of the new ADVENTURE EU projects, within the NEST - New and Emerging Science and Technology program (FP6), related to projects of high innovation, high risk, in high degree multidisciplinary research areas.
Labs & Projects:
Under these research areas he was a visiting research scientist for several International Laboratories, for brief periods. As an example: Imperial College - London, GeNeura - Granada Univ., DICMA/ELCOS, European Laboratory for Characterisation of Ornamental Stones - Bologna Univ., and RFV/INSA, Institut National des Sciences Appliqueés - Lyon. Co-founder of APGC "Portuguese Association on Knowledge Management (2004)", as well as aAAL "Artificial Life Art Architecture Lab.", Lisbon (2001), he is a member of ISGEC (Int. Society for Genetic and Evolutionary Computation), EU/ME (EUropean Chapter on MEtaheuristics EURO Working Group), ACFAS (Association Canadienne-Française pour l'Avancement des Sciences), EXISTENCE (Complex Systems European Network of Excellence), EVONET (The European Network of Excellence in Evolutionary Computing), ARTIST (Artificial Immune Systems Network), APRP (Pattern Recognition Portuguese Association), and APPIA (Artificial Intelligence Portuguese Association). Recently (March 2007), Aveiro Univ. Association of Physics (fisUA) have turned him one of his honorary members.