For Corvids together is better
A model of cooperation in Evolutionary Robotics

Michela Ponticorvo[1] Orazio Miglino[1,2] and Onofrio Gigliotta[2]

[1] Natural and Artificial Cognition Laboratory, University of Naples "Federico II", Italy
[2] Laboratory of Autonomous Robotics and Artificial Life, Institute of Cognitive Sciences and Technologies, National Research Council, Rome, Italy

Sommario In this paper we describe a model of cooperation in Evolutionary Robotics (ER) derived by animal research on Corvids. In recent years many researchers have proposed models of ER which are bio-inspired. The main source of inspiration has come from social insects, such as ants. Inspiration may come also from other representatives in the animal kingdom, that are quite different from insects such as primates or corvids, thus producing different models that can address different issues. The work presented here starts from works inspired by social insects and then describes an ER model which is built on corvids behavior, that addresses the evolution of cooperation, showing how different bio-inspired models can be useful to study different issues.

1 Introduction

In the first years of its life, Evolutionary Robotics (ER), [1, 2, 3] the fruitful technique for creation of autonomous robots based on the mechanism of Darwinian evolution, focused on the emergence of quite simple behavior such as obstacle avoidance or garbage collection [4] and on definition of its methods and techniques, for example the "simulate-and transfer method [5]. These efforts were meant to give a clear identity to this new-born discipline, which in subsequent years, was able to carve for itself an interesting and stimulating niche in the survey of scientific literature about Robotics and its application to Cognitive Science.
After this infancy period, researchers in ER started to look for methods which could lead to more and more complex behaviors. At this point they could choose between two alternatives: augmenting complexity inside the robot or augmenting complexity outside the robot. These alternative are expressed effectively by Izquierdo-Torres at the University of Sussex [6]: "Nature has been able to evolve (several times) natural systems which produce complex spatio-temporal patterns from agents with very simple behaviors by exploiting the interactions between the agents and their environment (...). In social insects large numbers of simple agents collectively achieve remarkable feats through exploiting a few principles. They offer a spectacular existence proof of the possibility of using many simple agents rather than one or a few complex agents to perform complex tasks quickly

and reliably. In other words, complex behaviors may result from one or two quite complex agents or from many very simple agents that interact with their environment and self-organize under evolutionary pressure. If we quickly review ER literature it seems quite evident that this second option overcame the first one. Collective Robotics [7, 8] is nowadays a consolidated frame of reference which aims at building multi-agent system in which robots are able to accomplish certain tasks by coordination among autonomous agents. In a certain sense, skills are distributed over a colony that must cooperate and communicate (also indirectly, in this case we refer to stigmergy in biological literature). In Collective Robotics agents self-organize producing complex, apparently intelligent structures, without need for any planning, control, or direct communication between agents. The main metaphor used is the swarm (shoaling, swarming or flocking), a term that is applied to fish, insects, birds and microorganisms, such as bacteria, and describes a behavior of an aggregation of similar organisms in which group size is a relevant factor. In the swarm the single agent is not important, only the swarm itself is relevant. This metaphor applied to Robotics generated the emergent field of Swarm Robotics [9, 10, 11, 12] that studies robotic systems composed of swarms of robots. The agents in the swarm are in close interact and cooperate to reach their goal, just like what happens in social insects. If we consider the phenomena of waggle dance of the honey bee, the nest-building of the social wasp and the construction of the termite mound, we must admit that is amazing that these seemingly uncommunicative, very simple creatures are able to manifest these behaviors. They are able to do this by relying on simple mechanisms that produce notable effects, such as the above cited stigmergy and self-organization. The swarm metaphor emphasizes the decentralization of the control, limited communication abilities among agents, use of local information, emergence of global behavior and robustness that are particularly consonant with ER principles. In a swarm robotic system, although each single robot of the swarm is fully autonomous, the swarm as a whole can solve problems that the single robot cannot cope with because of physical constraints or limited capabilities.

Social insects are undoubtedly a precious source of inspiration, but we should not restrict our attention on it, as challenging cues may derive from others representatives of the animal kingdom. In other word, following McFarland distinction [13], we should pay attention not only to eusocial behaviors (found in many insect species and resulting from genetically determined individual behavior) but also to cooperative behavior. In the case of cooperative behavior there are not many very simple agents that interact, but two or more quite complex individuals that work together to reach a goal that would be otherwise impossible to obtain. In nature there are many cases of this kind of cooperation: for example we can observe coalitions (help provided during conflicts) and alliances (long-term association) in many animals: primates (chimps, baboons, macaques, vervets, capuchins), carnivores (lions, cheetahs, hyenas) and dolphins. Between other animals coalitions and alliances have been described also in corvids [14]. In this case what we observe is a small number of corvids, each of which is capable

of refined cognitive abilities, that cooperate. They are an example of the first alternative we described, increased complexity inside the agent, that has not been exploited as much as the second one.
In the next section, we propose a simulation based on cooperation in corvids that will allow us to discuss the importance of different kind of cooperative models in ER.

1.1 Cooperation in Corvids

Corvids (*Corvidae*) family include various birds species characterized by high complexity in cognitive functions: they can be compared with primates both on brain relative dimensions, cognitive abilities and on social organization complexity [15, 16, 17]. They are capable of long term cache recovery, object permanence [18], tool manipulation, theory of mind like-abilities [19] and social reasoning. In nature we can observe them in dyads as well as in small or large colonies. Corvids are also able to cooperate in order to obtain a goal [20]. In the present study we propose a model that replicates in the main aspects the "loose string paradigm derived from the Game Theory, applied to comparative research. In the "loose string task two agents, for example two rooks (*Corvus frugilegus*), must cooperate to obtain a reward, i.e. food, which is clearly visible, but not directly reachable. The dyad gets the reward if the two tips of a string are pulled at the same time. In the present study we model this task with artificial organisms to study cooperation in artificial organisms.
In cooperation it is crucial to distinguish if dyads are "coordinated trough communication or acting apart together [21] It seems therefore quite relevant trying to understand how communication allows dyads to cooperate indeed.

1.2 The "loose string task

In the "loose string task two members of a dyad are trained to pull a string to reach a reward. In a first phase, the agents, for example, corvids such as rooks [20], are trained separately to pull the string which allows the bird the get the food by itself. In the cooperation testing phase, the two birds could get the reward only if they pulled the string at the same time (see Fig. 1). In this task the members of the dyad exchange signals mainly on the visual channel (private communication) thus indicating each other where they are. We reproduced this natural experimental task with simulated robots.

2 Materials and Method

2.1 The experimental set-up

The experimental setup involves two robots situated in a rectangular arena (1200 cm * 800 cm). Robots begin each trial at one end of the arena. On the other hand there are two target areas which robots must reach at about the same

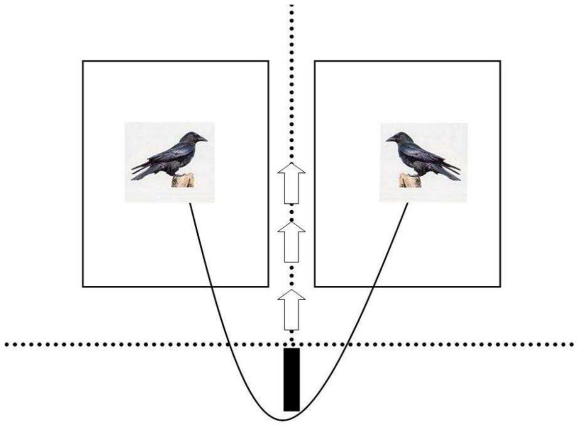

Figura 1. The loose string task: two rooks must pull the string together to get the reward.

time. This task represents a situation in which the robots should coordinate themselves/cooperate to get a reward.
To verify if robot did coordinate and didn't act apart together [21] we have run two simulations: in the first one robots could exchange signals on their relative position (see next section), in the second one they didn't communicate at all.

2.2 The robot and its artificial neural controller

The robots are two e-Puck robots [22], with a diameter of 7.5 cm provided with 2 motors which control the 2 corresponding wheels, 8 infrared proximity sensors located around the robot's body, a ground sensor and a turret to send and receive signals on distance and angle of the other robot. The neural controller of each robot is provided with sensory neurons, internal neurons with recurrent connections and motor neurons. These neurons allow to receive and produce signals that can be perceived by another robot. In detail in the sensory layer there are neurons that encode activation of infrared sensors, ground sensor and distance/angle sensors; in the hidden layers there are 4 hidden neurons with recurrent connections; in the output layer there are two units that control wheels.

2.3 The evolutionary algorithm

An evolutionary technique is used to set the weights of the robots' neural controller. The initial population consists of 100 randomly generated genotypes that encode the connection weights of 100 corresponding neural networks. Each genotype is translated into 2 neural controllers which are transferred in 2 corresponding simulated robots. The 20 best genotypes of each generation are allowed to reproduce by generating 5 copies each, with 2 % of their bits replaced with a

new randomly selected value. The evolutionary process lasts 100 generations (i.e. the process of testing, selecting and reproducing robots is iterated 100 times). The experiment is replicated 10 times each consisting of 4 trials (1000 cycles each) with different starting direction face on one hand of the arena.
We used the following fitness function to evolve robots: if both robots are on the target areas they are rewarded. This reward corresponds to (minus) time lapse between reaching the target area by the first robot and by the second one. We thus reward reaching the target area at the same time.

3 Results

3.1 Fitness values

In this section we compare the fitness values for two experimental conditions: with and without signals exchange. For each condition there are 10 replications with different seeds.
We compare the fitness value gained by the best robot of the last generation for each seed. The mean value for "with condition is higher than in "without condition: 97.16 (s.d. 18.23) versus 69.60 (s.d. 28.78); this difference was statistically significant: t test (9) = 2.83, p = 0.019.
Moreover, as the standard deviation is lower in "with condition, the presence of signals allows better and comparable results with different starting conditions.

3.2 Behavioural analysis

In this section we describe one two prototypical dyads, one "with and one "without signals accomplish the task.

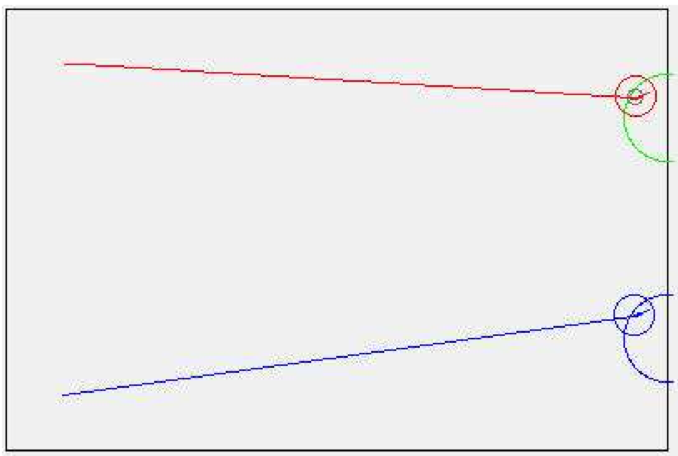

Figura 2. Trajectories of the dyad "with signals

Their trajectories are depicted in Figures 2 and 3. The dyad “with is perfectly able to coordinate: they wait for each other at the starting position, adjust their face-direction and go straight-on together up to the target areas. In the dyad “without, on the contrary, it is clear that each robot gets to the target area on its own. In other word, in presence of signals the robot is able to use this primitive form of communication to solve efficiently the task, while in absence of signal exchange neither this simple cooperative behaviour can emerge.

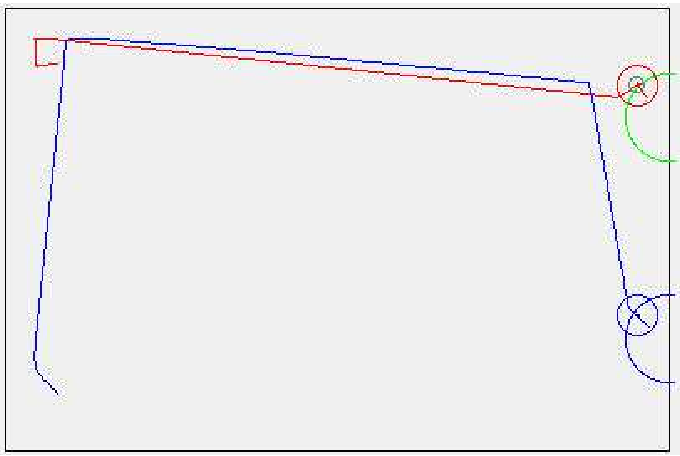

Figura 3. Trajectories of the dyad “without signals

4 Discussion and Conclusions

Results show that cooperation between robots is regulated by interaction between robots, with communication/signalling as a medium. In our simulative scenario the communication leads to a coordinated cooperation behavior that is somewhat similar to cooperation observed in natural organisms such as corvids. What we would like to suggest with the simple experiment described above is to establish a strong link with phenomena and tasks derived from experiments on animal behavior in order to get insight from this kind of data reciprocally. For this reason we modeled a well-defined experimental set-ups, that has been widely used in animal behavior literature and try to compare what happens in corvids’ cooperation with what happens in robots’ cooperation. This exchange can be fruitful both for researchers working with natural organisms and for researchers working with artificial organisms. One of the hint for Artificial-lifers may be the following: it is worth modeling more complex forms of cooperation. Different models of cooperation, in fact, may be used to study different issues: the first kind of models we introduced, with many simple agents, is useful to

study self-organization, stigmergy and other issues related to biology. The second kind of models allows us to study, for example, how signals can be used, how the other agent's position is represented, in other words issues that are more related to psychology and cognition.
In experiments about rooks, for example, authors talk about personality, a concept that cannot be dealt with swarm metaphor. Nonetheless understanding these problems, even if very difficult to face also with the models we have introduced above, could receive beneficial if modeling is inspired by complex natural occurring forms of cooperation, such as grooming in primates or human cooperation. More complex cooperation modeling should couple with insect metaphor, which is so powerful for many reasons. First of all, modeling insects' eusocial behavior is favorite because insects are much more similar to evolved robots in ER if compared with other animals. A simulated or physical e-puck robot can be imagined as an ant, for example, much more easily than as a primate. Moreover, this kind of modeling permits to address problems that represent nowadays the heart of research in Robotics in general and in Collective Robotics in particular, such as dynamical systems, distributed control, embodiment and situatedness, adaptive systems, coordination between autonomous agents, self-organization, etc. On the other side, trying to model agents or robots that are complex inside, would require a strong investment in Cognitive Science and from Cognitive Science that doesn't seem to be as strong as the previous one. The principal drawback in this kind of modeling is that, with actual techniques, it is still too difficult to build an agent that resembles in complexity natural organisms and this can be discouraging. One may object, for example, that the agents we used in our simulation are not at all comparable with corvids. This is undoubtedly true. In spite of this, this kind of bio-inspired models may be the first step in direction of modeling cooperation between complex agents: cooperation modeling may deepen our understanding of cooperation in group-living organisms and understanding cooperation in group-living organisms may allow to better understand how to build efficient artificial organisms.

Riferimenti bibliografici

1. I. Harvey, E. Di Paolo, E. Tuci, R. Wood and M. Quinn 'Evolutionary Robotics: A new scientific tool for studying cognition'. Artificial Life, 11(1/2), 79-98, 2005.
2. I. Harvey, P. Husbands, D. Cliff, A.Thompson and N. Jakobi 'Evolutionary Robotics: the Sussex Approach'. Robotics and Autonomous Systems, 20, 205-224, 1997.
3. S. Nolfi and D. Floreano, Evolutionary Robotics: The Biology, Intelligence, and Technology of Self-Organizing Machines. Cambridge, MA: MIT Press/Bradford Books, 2000.
4. S. Nolfi, D. Floreano, O. Miglino and F. Mondada. 'How to evolve autonomous robots: Different approaches in evolutionary robotics' in Conf. Artificial Life IV, 1994.
5. O. Miglino, H.H. Lund and S. Nolfi 'Evolving mobile robots in simulated and real environments'. Artificial Life, 2(4), 417-434, 1995.

6. E. Izquierdo-Torres. 'Collective intelligence in multi-agent robotics: Stigmergy, self-organization and evolution'. University of Sussex, 2004.
7. C.R. Kube and H. Zhang. 'Collective robotics: From social insects to robots'. Adaptive Behavior, 2(2):189-219, 1993.
8. R. Beckers, O.E. Holland and J.L. Deneubourg. 'From local actions to global tasks: Stigmergy and collective robotics'. In Proc. A-Life IV, MIT Press, 1994.
9. Beni G. and J. Wang. 'Swarm intelligence'. In Proceedings of the Seventh Annual Meeting of the Robotics Society of Japan, pages 425-428, Tokio, Japan, RSJ press, 1989.
10. E. Bonabeau, M. Dorigo, and G. Theraulaz. Swarm Intelligence: From Natural to Artificial Systems. Oxford University Press, New York, NY, 1999.
11. Y. U. Cao, A. S. Fukunaga, and A. B. Kahng. 'Cooperative mobile robotics: Antecedents and directions'. Autonomous Robots, 4:1-23, 1997.
12. J.-L. Deneubourg, S. Goss, N. Franks, A. Sendova-Franks, C. Detrain, and L. Chretien. 'The dynamics of collective sorting: Robot-like ant and ant-like robot'. In J.-A. Meyer and S. W. Wilson, editors, From Animals to Animats. Proceedings of the First International Conference on Simulation of Adaptive Behavior (SAB90), pages 356-365. MIT Press, Cambridge, MA, 1990.
13. D. McFarland. ' Towards robot cooperation'. In Proc. Simulation of Adaptive Behavior, 1994
14. N.S. Clayton, and N.J. Emery. 'The social life of corvids'. Current Biology, 17, R652-R656, 2007.
15. N.J. Emery. 'Are corvids 'feathered apes'? Cognitive evolution in crows, jays, rooks and jackdaws'. In Watanabe S (ed) Comparative analysis of minds. Keio University Press, Tokyo, 2004.
16. N.J. Emery and N.S. Clayton. 'Comparing the complex cognition of Birds and Primates. In Rogers LJ, Kaplan G (eds) Comparative vertebrate cognition: are primates superior to non-primates? Kluwer Academic/Plenum, New York, pp 3-46, 2004.
17. N.J. Emery and N.S. Clayton. 'The mentality of crows: convergent evolution of intelligence in corvid and apes'. Science 306:1903- 1907, 2004.
18. P. Zucca, N. Milos, G. Vallortigara. 'Piagetian object permanence and its development in Eurasian Jays (Garrulus glandarius)'. Animal Cognition, 10:243-58, 2007.
19. T. Bugnyar. 'An integrative approach to the study of ToM-like abilities in ravens'. Japanese Journal of Animal Psychology, 57, 15-27, 2007.
20. C. Scheid and R. Noe. 'Implications of individual temperament in a cooperative task', submitted.
21. R. Noe 'Cooperation experiments: coordination through communication versus acting apart together'. Animal Behaviour, 71, 1-18, 2006.
22. F. Mondada, M. Bonani. The e-puck education robot. http://www.e-puck.org/, 2007