Emergence of Collective Escaping Strategies of Empathic Caribou Agents in Wolf-caribou Predator-prey Problem

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ABSTRACT

We investigate an approach of applying Genetic Programming for evolution of optimal escaping strategies of a team of caribou agents in the wolf-caribou predator prey problem (WCPPP). The considered case of WCPPP comprises a team of eight caribou agents that attempts to escape from a single yet superior (in terms of sensory abilities, raw speed, and energy) wolf agent in a simulated two-dimensional infinite toroidal world. We empirically verified our hypothesis that the incorporation of empathy in caribou agents significantly improves both the efficiency of evolution of the escaping behavior and the effectiveness of such a behavior. This finding could be seen as a verification of the survival value of empathy and the resulting compassionate behavior of the escaping caribou agents. Moreover, considering the fact that a single caribou could never escape from the superior wolf, the ability of the team of empathic caribou agents to escape could also be viewed as an illustration of the emergent nature of successful escaping behavior – in that the team-level properties are more than a mere sum of the properties of its individual entities.

KEYWORDS

Collective Behavior, Empathic Agents, Genetic Programming, Wolf-caribou, Predators-prey Pursuit Problem, Multi-agent Systems

1. INTRODUCTION

As ancient Greek philosopher Aristotle (384 BC – 332 BC) noted, “The whole is greater than the sum of its parts.” This principle applies well to various aspects of science, technology and engineering. In our research we attempt to verify this principle in the domain of multi-agent systems (MAS) employed for modelling of an artificial society. As an instance of such an artificial society, we consider the wolf-caribou predator prey-problem (WCPPP), which was originally studied by Tian, Tanev and Shimohara [1][2]. WCPPP is an instance of heterogeneous MAS featuring two types of agents – one superior wolf agent (predator) and multiple (inferior) caribou agents (prey) that are required to escape from the chasing wolf. The problem is defined to be inherently cooperative in that the inferior caribou agents could not escape from the superior wolf unless they cooperate with each other. The WCPPP could be viewed as a reversed case of the well-studied predator-prey pursuit problem, as the latter comprises a team of multiple (inferior) predators that are required to capture a single (superior) prey.

The *objective* of our work is to investigate the feasibility of applying genetic programming to evolve the escaping behavior of caribou agents. Moreover, we intend to verify whether the empathy, incorporated in caribou agents would improve the efficiency of evolution of their behavior or the effectiveness of such a behavior.

In principle we could be able to develop the behavior of caribou agents applying a top-down approach of mapping the perceptions of the agents into desired actions. Due to the complexity of the system, however, we would

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be unable to infer the required behavior of the entities (caribou agents) from the desired team-level escaping behavior. The relationships between the properties at these two levels of the system are nonlinear, too complex, and too difficult to be formalized. Hence, we would rely on genetic programming as both a holistic and heuristic approach to develop such a behavior. The methodological holism implies that while evolving the (lower level) behavior of the caribou agents, we would be able to evaluate its quality from the (higher level) properties of their *whole* team, namely, from their ability to escape from the chasing wolf. On the other hand, the heuristics of the proposed approach would mean that in order to develop the escaping behavior of the caribou agents, we would rely on an a simulated evolution as a variant of an automated trial-and-error-correcting approach, rather than on formal models of the properties of agents and their environment.

Compared to the work of Tian, Tanev and Shimohara [1][2], in our work we propose a more plausible energy model of caribou agents, and investigated the resulting emergent escaping behavior of the team of caribou agents.

The remaining of our article is organized as follows. In Section 2 we define the WCPPP and present the proposed abstract architecture of the caribou agents. In Section 3 we elaborate on the evolutionary framework and its parameters. Section 4 presents the experimental results. Finally, Section 4 draws a conclusion.

2. THE PROBLEM AND THE PROPOSED ARCHITECTURE OF AGENTS

2.1 WCPPP

The proposed instance of WCPPP comprises two types of agents: a single predator wolf agent and multiple caribou agents (Figure 1). The task of wolf agent is to capture at least one caribou during the limited number of time steps of the trial, while the task of caribou is to prevent this from happening. In our work we consider an instance of the problem, which is more realistic than the commonly investigated in the past [3][4][5]. We model the world as a two-dimensional continuous (infinite) torus visualized as 2D-surface with simulated (scaled) dimensions 1800m×1800m.

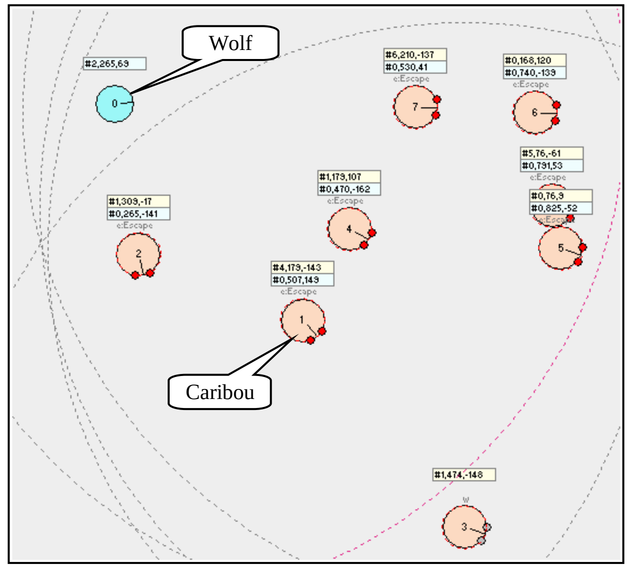

Figure 1. A snapshot of the world of WCPPP comprising one wolf and eight caribou agents.

The moving abilities of caribou agents are continuous too, and they can turn left and right to any angle from their current heading and can run with speed equal to 0, 0.25, 0.5, 0.75 and 1.0 of maximum speed. The wolf can run at its maximum speed when chasing the closest caribou. Furthermore, all agents feature an energy level witch is a factor (equal to one at the beginning of the trial) in calculating the actual running speed of the agents. The energy level decreases linearly with the distance traveled by the agents.

The perceptions of caribou agents are based on proximity perception model in that they can only see (i) the closest peer agent, (ii) the chased caribou agent, and (iii) the wolf, and only if these are within the limited range of visibility of the simulated sensors. The wolf agent can see (and chase) only the closest caribou and only if the latter is within the range of its sensors. The visual field of sensors of both the caribou and wolf are 360 degrees.

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The task of caribou is inherently cooperative in that they could not escape from the wolf unless they cooperate with each other. Indeed, the wolf is superior to the caribou in terms of sensory abilities (range of sensors), raw speed, and energy. The main parameters of wolf and caribou agents are illustrated in Table 1.

Table 1. Main parameters of wolf and caribou agents

Parameter	Wolf	Caribou
Number	1	8
Range of sensors	900 m	660 m
Visual field of sensors	360 degrees	360 degrees
Max speed	19 m/s	17 m/s
Initial energy	150 units	100 units

2.2 Architecture of Caribou Agents

We adopted the subsumption architecture of the Caribou agents consisting of functional modules distributed in three "levels of competence" in the overall behavior of caribou agents: *wandering* (lowest priority), *escaping* from wolf and *social behavior* (highest priority) – coordinated movement aimed at *distracting*, or *deceiving* the chasing wolf.

The random *wandering* and *escaping* are straightforward behaviors, and we handcrafted them in the functionalities of the caribou agents. However, *social behavior* of each of the caribou agents is the type of behavior that actually accounts for the behavior of other entities, and that, consequently, would contribute to the emergence of the higher (team-) level escaping behavior. Due to the complexity of relationship between the low level and high-level properties of MAS, we propose an approach of employing genetic programming for evolution of this behavior. The details of the evolutionary framework are elaborated in the following section.

3. EVOLUTIONARY FRAMEWORK

3.1 Sets of Functions and Terminals

We model the reactive behavior of caribou agents as an evolvable set of stimulus-response behavior rules. Such a reactive behavior of caribou agents could be, in principle, evolved using various nature-inspired techniques, including genetic algorithms, genetic programming (GP) and artificial neural networks. GP is a domain-independent problem solving paradigm in which a population of individuals (encoded as computer programs) is evolved – by means of modeling the Darwinian principle of reproduction and survival of the fittest – to solve various design and optimization problems. In GP genetic programs (individuals) are typically represented as parse trees whose nodes are functions, variables or constants. The nodes that are roots of sub-trees are non-terminals - they represent functions. The sub-trees of the functional nodes correspond to the arguments of the function of that node. Both the variables and the constants are terminals – they do not require arguments and they always are leaves in the parse tree. The set of terminals includes the perceptions (stimuli) and actions (responses) the caribou is able to perform. The function set consists of the logical `IF-THEN` function that maps certain stimuli into corresponding response(s), arithmetical and comparison operators. The function- and terminal sets of the proposed GP used to evolve the caribou agents are shown in Table 2.

3.2 Representation of Genetic Programs

Motivated by the expressiveness, flexibility and the wide-spread adoption of the Extensible Markup Language (XML) and Document Object Model (DOM), we employed the XML-based genetic programming framework (XGP), in which the evolved genetic programs are represented as DOM-parsing trees with their corresponding flat XML texts [6].

3.3 Genetic Operations: Selection, Crossover and Mutation

As a selection mechanism, we use binary tournament selection. It has proved to be both simple to code and computationally efficient. We implemented a strongly typed crossover in that only the nodes (with the corresponding subtrees) of the same data type (i.e. labeled with the same XML-tag) from the selected parents could be swapped [7][8]. The random sub-tree mutation is also implemented in a strongly typed way in that a random node could be replaced only by randomly created syntactically correct sub-tree. The mutation operation checks the type of the modified node and applies a randomly chosen syntax rule from the set of applicable rules as defined in the grammar of XGP.

Table 2. Function- and Terminal Sets of GP

Category		Designation	Explanation
Function set		IF-THEN, LE, GE, WI, EQ, NE, +, -	IF-THEN, ≤, ≥, Within, =, ≠, +, -
Terminal set	Sensory abilities	Wolf_d	Distance to the wolf
		Wolf_a	Bearing (angle in the visual field) of the wolf
		Speed_Wolf	Speed of wolf
		Peer_d	Distance to the closest caribou
		Peer_a	Bearing (angle in the visual field) of the closest caribou
		Speed	Own speed
		Speed_Peer	Speed of the closest caribou
		Chased_Peer_d*	*Empathy:* Distance to the *chased* caribou
		Chased_Peer_a*	*Empathy:* Bearing (angle in the visual field) of the *chased* caribou
		Speed_Chased*	*Empathy:* Speed of the *chased* caribou
		Chased	*True* if caribou is the chased one; *False* otherwise
		Faster_than_ Chased*	*True* if own speed is higher than the chased caribou; *False* otherwise
	State variable	Speed	Speed of the agent, *m/s*
	Ephemeral constants	Integer	Random value within [0…10]
	Moving abilities	Turn(α)	Turns from the current orientation to α degrees (α>0 means clockwise)
		Stop, Go_1.0	Stops the caribou, or sets the speed to max value, respectively.
		Go_0.25, Go_0.5, Go_0.75	Sets speed to 0.25, 0.5, and 0.75 of maximum

*Perceptions correspond to caribou agents with empathy

3.4 Breeding Strategy

The breeding strategy (applied to the evolved caribou agents only) is homogeneous: a single genetic program is cloned to all the caribou agents. The fitness of the whole team of homogeneous caribou agents is then evaluated during the fitness trial.

3.5 Fitness Evaluation

In order to obtain more general escaping behaviors of the caribou agents, the fitness of each genetic program is evaluated as an average of the fitness values obtained from all 10 initial situations. In each of these initial situations the wolf is placed at a random position in the world and with random orientation. The caribou agents are positioned at a random distance from the wolf between 300m and 500m, i.e., within the range of visibility of the wolf. The fitness value of each of these situations is defined as the time needed for the wolf to capture any caribou. The maximum (i.e., best possible) fitness value would correspond to the number, equal to the maximum number of the time steps of the trial, i.e., 600. Notice that the team of caribou is explicitly rewarded for escaping the wolf (for maximizing the total time of the fitness trial) rather than for exhibiting particular traits of eventual escaping behaviors. The escaping behavior, being “invented” during the simulated evolution, should emerge from the relatively simply defined perception- and moving abilities of the caribou agents. The main parameters of the proposed GP are shown in Table 3.

Table 3. Main parameters of GP

Parameter	Value
Population size	400
Selection mechanism	Binary tournament
Selection rate	10%
Mutation mechanism	Random subtree mutation
Mutation rate	5%
Elitism	4%
Fitness trial	Over 600 time steps, for 10 different initial situations
Fitness value	Average time steps (per initial situation) required to capture a caribou. Fitness value equal to 600 indicates a successful escape of caribou in all 10 initial situations.
Termination criteria	((Fitness=600) AND (Successful situations=10)) OR (No fitness improvements for 60 generations)

4. EXPERIMENTAL RESULT

4.1 Evolution of Team of Caribou Agents without Empathy

We conducted 20 independent runs of XGP in an attempt to evolve a successful escaping behavior of the team of 8 caribou agents *without empathy*. Within the considered context of the WCPPP we view the empathy as the ability of the caribou that are not currently chased by the wolf to understand and share the feelings of the chased one. Without incorporating any empathy, the perceptions of caribou agents include the distance and bearing of the wolf and the closest peer (as indicated in Table 2). The dynamics of the number of successful situations for these runs is shown in Figure 2. As Figure 2 illustrates, in none of the 20 runs of GP the team of caribou agents is able to escape in all 10 initial situations. In average (shown as dashed line in Figure 2), the team of caribou agents escapes only in about 2 (of 10) initial situations.

4.2 Effect of Empathy on the Efficiency of Evolution and Effectiveness of Evolved Escaping Behavior

We conducted additional 20 runs of XGP to evolve a successful escaping behavior of the team of 8 *empathic* caribou agents. We incorporated the empathy by introducing additional perceptions that allow the caribou agents to perceive the distance and bearing of the currently chased caribou (refer to Table 2). Notice that introduction of empathic perceptions does not automatically imply an emergence of compassionate behavior, i.e., that the caribou will use these perceptions in order to help the chased peer. The compassionate behavior should be eventually discovered by the simulated evolution providing that such a behavior brings a certain survival value to the team of caribou agents. The dynamics of the number of successful situations for 20 runs of GP evolving a team of 8 empathic caribou agents is shown in Figure 3. As Figure 3 illustrates, the maximum number of initial situations is 10, and in 17 out of 20 runs (i.e., in 85% of runs) the team of empathic caribou is able to escape in all 10 initial situations. In average (shown as dashed line in Figure 3), the team escapes in about 9 (of 10) initial situations.

The obtained results suggest that with emphatic agents, the evolution is both more efficient (i.e., the same number of successful situations are attained faster than in the team of non-emphatic caribou) and the emerged escaping behavior if more effective. The average number of successful situation is much higher – 9 vs. 2 – than in the team of non-emphatic caribou.

4.3 Consumption of Energy by Wolf and Caribou Agents

In order to investigate the dynamics of the energy consumption by wolf and caribou agents in both cases (caribou agents without- and with empathy) we plotted the energy level of entities at each instant of two sample trials: (i) an unsuccessful situation for a team of caribou agents without empathy (Figure 4) and (ii) a successful escape of a team of empathic caribou agents (Figure 5). As Figures 4 and 5 illustrate, by the time the caribou of non-empathic team is captured (around time step #371 shown in

Figure 4) the wolf features significant energy superiority over all caribou agents. In contrast, at the same time (time step #371, Figure 5) the wolf enjoys relatively insignificant superiority over the energy levels of some of the empathic caribou agents. We speculate that the reduced energy superiority of the wolf over (at least) some of caribou agents is relevant for the success of their escaping behavior.

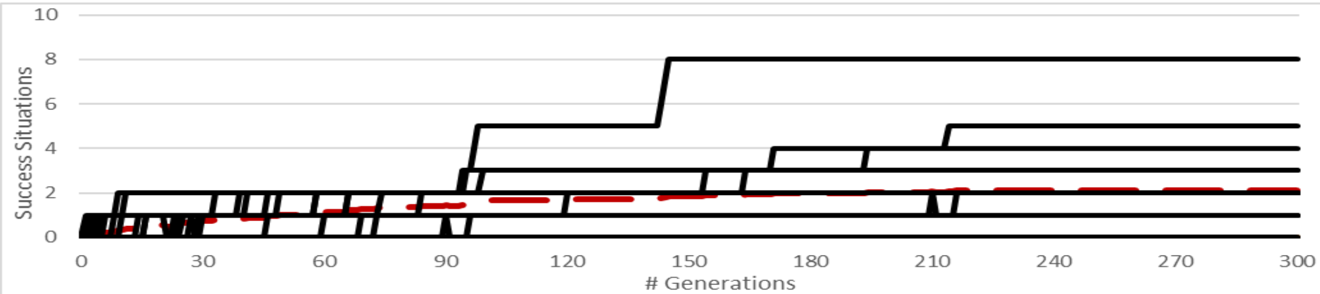

Figure 2. Dynamics of the number of successful situations for 20 independent runs of GP evolving a team of 8 caribou agents *without empathy*. The maximum number of initial situations is 10, and in none of the 20 runs of GP the team of caribou is able to escape in all 10 initial situations. In average (shown as dashed line), the team escapes in about 2 (of 10) initial situations.

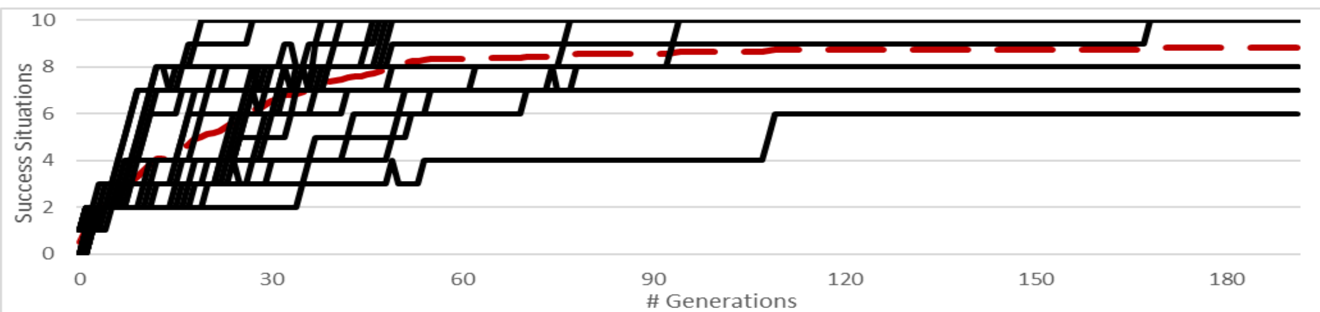

Figure 3. Dynamics of the number of successful situations for 20 independent runs of GP evolving a team of 8 *empathic* caribou agents. The maximum number of initial situations is 10, and in 17 out of 20 runs of GP the team of caribou is able to escape in all 10 initial situations. In average (shown as dashed line), the team escapes in about 9 (of 10) initial situations.

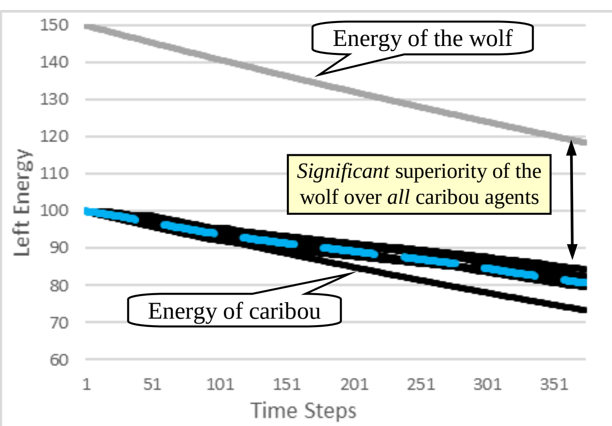

Figure 4. Dynamics of the energy levels of all agents with caribou *without empathy* during a sample *unsuccessful* (i.e., a caribou agent is caught at time step #371) trial. Dashed line represents the average energy of all caribou agents.

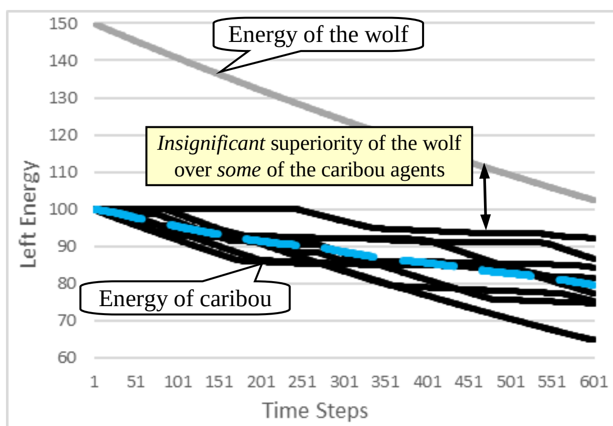

Figure 5. Dynamics of the energy levels of the agents *with empathic* caribou during a sample *successful* trial (i.e., wolf is unable to catch any caribou by the end of the trial at time step #600). Dashed line represents the average energy of all caribou agents.

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4.2 Emergent Escaping Behavior of the Team of Empathic Caribou Agents

A sample emergent escaping behavior of the team of empathic caribou agents is shown in Figure 6. The behavior exhibits the following strategy:

- A compassionate *Caribou #i* spares its own energy by moving slowly towards the escaping path of the chased *Caribou #j*.
- As *Caribou #j* approaches *Caribou #i*, the latter stops moving in order to expose itself closely to the chasing wolf.
- The wolf switches its attention from the exhausted *Caribou #j* to the currently closest (yet, energetically fresher) *Caribou #i* which allows the *Caribou #j* to escape.

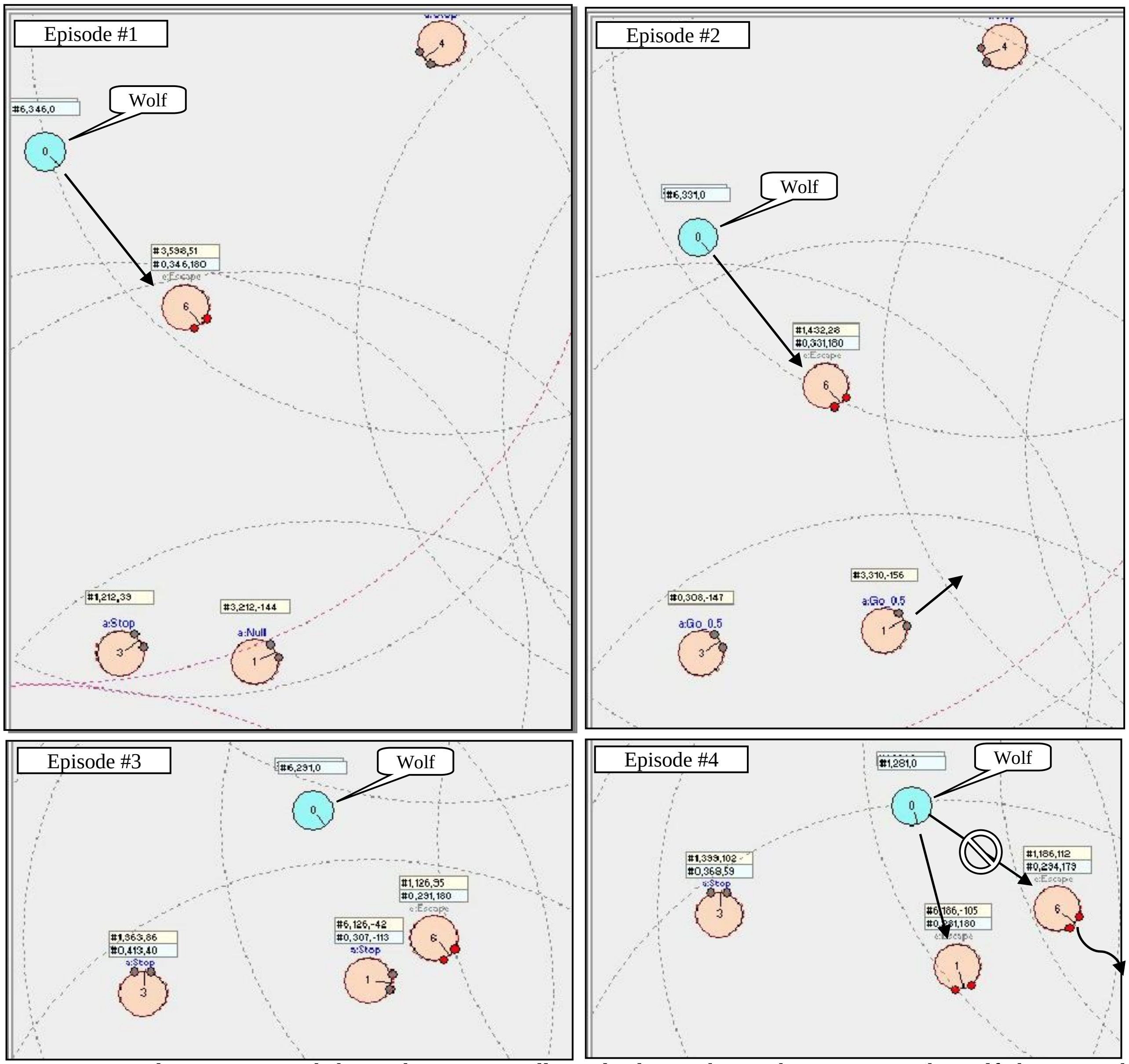

Figure 6. Emerged compassionate behavior by automatically evolved empathic caribou agents: as the wolf chases *Caribou #6*, *Caribou #1* saves energy by moving slowly towards the escaping path of the chased *Caribou #6* (Episodes #1 and #2). As the *Caribou #6* approaches *Caribou #1*, the latter stops moving in order to expose itself as the closest to the chasing wolf (Episode #3). The wolf switches its attention from the exhausted *Caribou #6* to the currently closest (yet, energetically fresher) *Caribou #1* (Episode #4) which allows the *Caribou #6* to escape.

5. CONCLUSION

We demonstrated the feasibility of evolving (via genetic programming) the escaping strategies of a team of caribou agents in the wolf-caribou predator prey problem. The latter comprises a team of eight caribou agents that is required to escape from a single yet superior wolf agent in a simulated two-dimensional toroidal world. We experimentally proved the survival value of empathy in that its incorporation in caribou agents significantly improves both the efficiency of evolution of the escaping behavior and the effectiveness of such a behavior. Moreover, because a single caribou could never escape from the superior wolf, the very ability of the team of empathic caribou agents to escape could also be seen as an illustration of the emergent nature of successful escaping behavior – in that the higher (team-) level properties are more than a mere sum of the properties of its individual entities.

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