

# The Evolution of Affect-Related Displays, Recognition and Related Strategies

Robert Lowe, Lola Cañamero, Chrystopher L. Nehaniv and Daniel Polani

Adaptive Systems Research Group

School of Computer Science, University of Hertfordshire  
College Lane, Hatfield Herts AL10 9AB, United Kingdom  
{R.Lowe, L.Canamero, C.L.Nehaniv, D.Polani}@herts.ac.uk

## Abstract

This paper presents an ecologically motivated, bottom-up approach to investigating the evolution of expression, perception and related behaviour of affective internal states that complements game-theoretic studies of the evolutionary success of animal display. Our results show that the perception of displays related to affect greatly influences both the types of display produced and also the survival prospects of agents. Relative to agents that do not perceive rival agent internal state, affect perceivers prosper if the initial environment in which they reside provides numerous opportunities for interaction with other agents and resources. Conversely, where the initial environment with sparse resources does not allow for regular interaction, ability to perceive affect is not as facilitatory to survival. Furthermore, the agents evolve particular display strategies distorting the expression of affect and greatly influencing the proportion of affect perceiving to non-affect perceiving agents over evolutionary time.

## 1 Introduction

Expression of internal and external attributes as a possible precursor to communication has been the subject of much ethological and biological research. The animal kingdom provides us with numerous functional examples of animals using stereotyped displays to encourage observers to focus on particular attributes. Stotting behaviour in gazelles, for example, has been explained [11] as the sending of a message to a would-be predator that it should not waste its energy in attempting to catch such a vigorous gazelle. Cephalopods may use finely modified patterned visual displays in courtship rituals, for defence from predators (e.g. via crypsis), for predation and in antagonistic contests [14]. Cephalopod colour patterns are directed by neuronal and physiological change which allows for the subtle and speedy deviations in skin colour, patterning and shading that are crucial for their survival and reproduction.

Theoretical biology in the form of game theoretic models has similarly tended to focus on the functional behavioural component of communication where the pay-offs for using certain antagonistic behavioural strategies associated with displays are proposed. Examples include the “Hawk vs Dove” model of Maynard Smith and Price cited in [11] and

the Enquist-Hurd contest pay-off matrix [12, 16, 13]. In the case of the latter model, pay-offs are calculated for animals producing distorted displays of actual strength which perceiving agents are assumed to interpret as honest. Applications of game theoretic models to communicative expression have generally been limited to field observations (e.g. red deer stags and the handicap principle [7, 8]) and dynamic simulation environments [17]. In the latter research, the applicability and limitations of the Enquist-Hurd game theoretic model were investigated; however, studies of this type are unavoidably constrained by the need to trade off empirical validity with faithful adherence to an often rigid and simplistic model.

The evolution of communication and its precursors in behavioural interactions [23, 22, 19] resonates with the area of ethology. Of the four essential aspects Tinbergen [23] defines, game theoretic models have concentrated on ‘function’ whereas ‘mechanism’, ‘ontogeny’ and ‘phylogeny’ have been largely neglected. Noble [20], for example, argues that function – the adaptive value of a given behaviour – can be studied independently from mechanism – the underlying physiological processes that give rise to physical behaviours. However, since affect refers to internal states such as motivations, drives and emotions, affective state may be modelled mechanistically and hypothesised to be of significant relevance to communication and signalling – and consequently to function. Indeed, affect related expression – an example of co-dependence between mechanism and function – has stimulated interest in psychologists [21] since the discoveries of Charles Darwin [9] and is an area of growing research emphasis among modellers of Artificial Intelligence [4, 10, 5]. The importance of affect to signalling and display is stated by Hauser [15], who suggests that “in a majority of species, affective states are responsible for the production of communicative signals”.

While research into affective robots [10, 5] exploits the functional communicative value of affective expression, research with regard to group dynamics has been largely confined to psychological and ethological study. The evolutionary origin and development of such expression – which

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refers to Tinbergen's 'phylogeny' – has been the subject of investigation since Darwin; however, attempts to replicate the emergence and evolution of expressive and perceptive strategies over evolutionary time are lacking.

The current paper reports the initial findings of research into the use and distortion of affect expression on agent performance in a dynamic, 'season-based' environment. The research assesses the performance of *affect perceiver* agents versus *generic perceiver* agents, blind to displays of affect. Both types always express affect. Evolving expression of internal state was analysed in order to gauge the emergence and development of display strategies. Two hypotheses were made: 1) agent mortality will be influenced by ability to perceive affect in other agents, 2) displays of affect will evolve in ways that influence the proportion of surviving affect perceivers and generic perceivers. The layout of the paper is as follows: Section 2 describes the dynamic simulation environment used, the agent behavioural repertoire and action selection architecture governing behaviour. Section 3 details the performance of the two types of agent over evolutionary time with respect to behaviour and viability. Section 4 offers concluding remarks.

## 2 Agent Architecture and Environment

### 2.1 Environment Configuration

Our 2-D toroidal, continuously spaced, discretely timed environment consists of food resources and competing, reproducing, asexual agents. Agents perceive and display colours that carry information about internal state. Internal state is determined by the interactions among a behaviour-based architecture, an internal physiology and a set of motivational states, similar in spirit to [6, 2]. Following the common distinction used in ethology [18], the behavioural repertoire of agents includes both *consummatory* (goal-achieving) and *appetitive* (goal-seeking) behaviours. Agents' consummatory behaviours include *eat*, *hit* and *escape* while appetitive behaviours include *look for food* and *look to attack*.

### 2.2 Action Selection Architecture

Agents' decision making is governed by a "voting based" action-selection architecture, following [1, 3]. The main elements of the architecture are survival-related: homeostatic physiological variables, motivational states and behaviours.

These aspects of the architecture serve to link rival agent affect to perceiving agent affect through the influence of perceived affective state on perceiver motivational state and consequent displays and behaviour.

Agents have two physiological variables, 'energy'  $E$  and 'social stimulation'  $S$  that they need to maintain within viable bounds and that decrement by default, i.e. in the absence of any external stimuli. Motivations are urges to action that combine drives to correct physiological errors (deviations from the homeostatic ideal physiological value) and the perceived value of external stimuli: rival agents or food

Rival agents whose perceived affective state indicates that they represent a threat will strongly influence the perceiving agent's motivational states. Consummatory and appetitive behaviours are carried out as a result of a solitary 'winner' behaviour being selected owing to a combination of the likelihood of them satisfying to the greatest extent all the motivations that contribute to its selection and the extent to which they correct associated physiological errors. Consummatory behaviours *eat* and *hit* help agents satisfy motivations to increase  $E$  and  $S$ , respectively, and to avoid death through exhaustive depletion of these two variables. An *escape* behaviour serves to allow agents to avoid a potentially life-threatening excess of  $S$ . Appetitive behaviours allow agents to continue their search for food or other agents.

The physiological variables are abstractions and not meant to be (strictly) biologically plausible. However, the use of these variables serves to create the sort of conflicting pressures appropriate to the emergence and evolution of signalling strategies. This owes to the need to satisfy motivations via behaviours that drive the physiological variables towards their homeostatic ideals. In the current simulation environment agents are thus required to trade off the utilisation of two resources, food and other agents, since neither resource serves to correct errors in both physiological variables.

Scarcity of resources and a fast metabolism ensure a need for agents to compete in order to survive and reproduce at the end of each generation. Being able to perceive the affective state of another agent, in this respect, may provide a competitive advantage since a rival agent who is in  $S$  excess will not be motivated to attack and therefore would not represent a survival threat since a further increase in  $S$  could lead to its death. The affect perceiving agent is then more able to select the pay-off optimising behaviour in a given interaction.

The external rival agent stimulus is calculated by affect perceivers using an objective measure of rival agent depiction of  $E$  and  $S$  values via colour saturation and hue respectively. Generic perceivers, on the other hand, attribute a fixed value to all rival agents for both  $E$  and  $S$ . This evolves over generational time to a potentially more adaptive value.

### 2.3 Expression and Recognition

Agents have two sensors: 1) 'stalker' detector, and 2) vision. In the case of 1) agents are able to detect the presence of unseen rival agents in close proximity. On detection of such rival agents, the perceiving agent will abruptly turn around and evaluate the threat or resource value of the rival using a forward-facing discretized visual field. Affect perceiving agents view colour hue and saturation, which in generation 1 of each simulation run faithfully reflect the physiological variables  $S$  and  $E$ , respectively. The use of colour, while not being an attempt at faithful colour modelling in biological agents, relates at an abstract level to cephalopod display

behaviour. In both cases, the physiological component of affect influences visual expression and its perception. Additionally, agents can potentially flash displays at rival agents when they are looking for food or to attack.

## 2.4 Evolving Displays

Displays represent deviations from the faithful 1:1 mapping of internal physiological state to colour configuration. This occurs over evolutionary time as a consequence of a 100 percent rate of small mutations of the mapping of the two physiological variables to dimensions of colour. There are a total of four agent displays from which one is selected in the presence of a stimulus. The two display-inducing appetitive behaviours (looking for food, looking to attack) each have a pair of weights pertinent to the types of stimuli present: agent, or agent and food. Display values are derived via a calculation relating to the direction of deviation from the faithful mapping (i.e. exaggerated or inhibited depiction of  $S$  value). Only the display of  $S$  value and not  $E$  can be affected and thus distorted by mutation.  $E$  (expressed faithfully as colour *saturation*), influences visual search for resources rather than targetted agent search. Displays are calculated via use of the following equation which determines the extent to which an agent can exaggerate or inhibit depicted  $S$  value:

$$\text{hue} = \begin{cases} W_1 > W_2 & : S + (1 - S) * (W_1 - W_2) \\ W_1 \leq W_2 & : S - S * (W_2 - W_1) \end{cases}$$

where *hue* corresponds to the updated colour hue, and  $W_1$ ,  $W_2$  are weight values for exaggerated and inhibited depictions of physiological values, respectively. High evolved values of  $W_1$  relative to  $W_2$  and vice versa could lead to what observers might interpret as ‘bluff’ and ‘trojan’ strategies respectively [16]. A ‘bluffer’ has its hue value exaggerated relative to the actual  $S$  value. Conversely a ‘trojan strategist’ has a reduced hue depiction of  $S$ . The more the display value deviates from zero, the less accurate is the depiction of affective state. In general, it might be expected that a ‘bluff’ display would be adaptive to agents looking to avoid conflict whilst a ‘trojan’ display would enable aggressive agents to attack unsuspecting agents more easily.

## 3 Experiments, Results and Analysis

### 3.1 Experimental Set-up

Simulations are run over 30 generations of 10000 time steps on a JBuilder Applet. The artificial life simulation environment is initialised in every run with one of two possible food resource configurations: 1) distribution clustered with quantity relatively abundant (*summer*), 2) distribution scattered with quantity relatively scarce (*winter*). Each simulation run consists of 30 generations and half way through each generation, resource configuration changes from 1) to 2) or vice-versa to increase environmental dynamism. Out of a total of

100 runs, half are initialised with configuration 1) and half with 2) to control for order effects. The first generation of every simulation run is initialised with a fixed population of 80 agents (40 affect perceivers and 40 generic perceivers). Such a population size allows for a sufficient number of survivors at the end of each generation to minimise the potential effects of drift convergence. Surviving agents contribute an equal number of asexually produced offspring to the next generation of agents. Inherited continuous parameters in  $[0,1]$  for generic perceived stimulus (colour) values, agent type (i.e. affect perceiver or generic perceiver) and display values for different stimulus configurations are all subject to mutation.

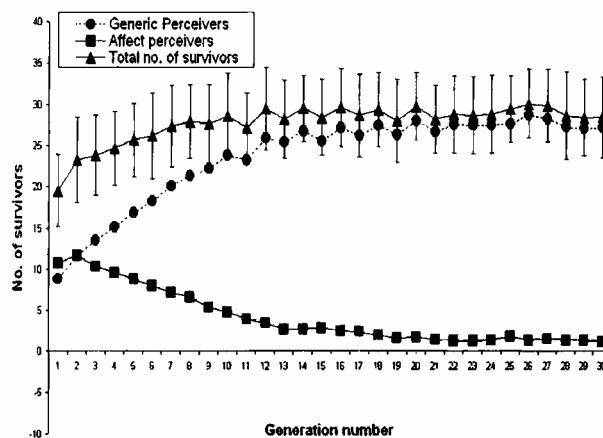


Figure 1: Graph of affect-perceiver, generic-perceiver and all agent average survivor rate over 30 generations in winter-first condition (average of 50 runs).

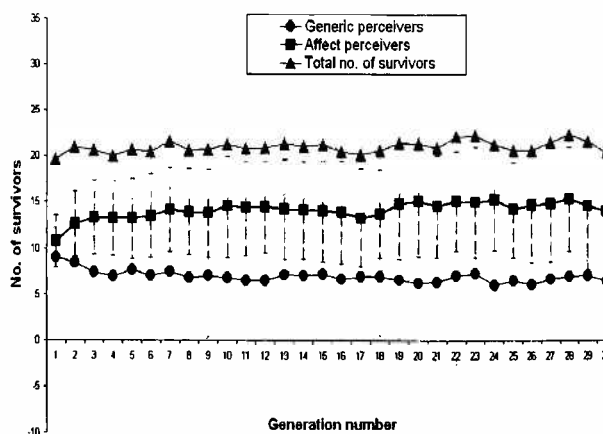


Figure 2: Graph of affect-perceiver, generic-perceiver and all agent average survivor rate over 30 generations in summer-first condition (average of 50 runs).

### 3.2 Results Summary

Fig.1 and Fig.2 depict the average numbers of agent survivors of affect perceiver and generic perceiver type and the applicable standard deviation error bars over all simulation runs. Fig.2 shows that affect perceiving agents, on average, outperform the generic perceivers when the first season encountered is summer. Fig.1 indicates that affect perceiving agents perform considerably worse than generic perceiving agents when winter precedes summer. While the standard deviation error bars in Fig.2 overlap the fact that the summer-first results showed affect perceivers outperforming generic perceivers on 40/50 occasions suggests that there is a strong bias towards affect perceiver survival success. Winter-first results showed generic perceivers outperforming the affect perceivers in 50/50 runs. Therefore, ability to perceive affect greatly influences survival prospects in accordance with *hypothesis 1*.

These results suggest that the adaptive value of affect perception is dependent on the order of seasons. Since the effects on survival of the first season influence survival prospects in the following season, it might also be extrapolated that the value of affect perception is environment dependent, i.e. dependent on the number and distribution of resources. Interestingly, in both conditions affect perceivers tend to outperform, on average, the generic perceivers in the first two generations. In the summer-first condition the affect perceiver survivor mean equals 10.72 compared to 9.04 for generic perceivers after the first generation. In the winter first condition affect perceiver mean equals 10.74 and generic perceiver mean equals 8.8. Agents with indiscriminate, generic perception of rival agents are seemingly disadvantaged by a lack of affect perception in initial generations. Generic perceivers may benefit, however, from evolving an agent stimulus value that is, averaged over agent interactions, more conducive to adaptive behaviour. Affect perceiving agents, with their more circumspect evaluation of external stimuli, at least in early generations, out-perform generic perceivers with respect to survival over the two seasons.

### 3.3 Evolution of Generic Perceivers

The tendency for generic perceivers to proliferate over time in the winter-first condition may owe to the fact that, with a lesser prospect of encountering agents with which to socially interact (owing to an absence of food clusters around which agents gather, as in the summer condition), there is a greater need to 'take the risk' and attack opportunistically or generically. Attributing generic stimulus values of excess  $S$  (i.e.  $S$  values above the 0.5 homeostatic level) to rival agents increases the likelihood that such generic perceivers will attack owing to the hard-wired nature of the agent action-selection architecture. Note that agents are only motivated to 'hit' if their own  $S$  values are in deficit and therefore when in  $S$  excess they do not represent a threat. In the winter-first condition, generic perceivers evolve, over time, to

stimulus values conducive to 'hitting'. By generation 30, the  $S$  value, generically attributed, evolves to 0.7 with standard deviation just 0.04. The mean attributed  $E$  value of 0.3 (with standard deviation a very low 0.1) is that which the agents attribute to all other agents indiscriminately. The low standard deviations indicate a strong pressure over the 50 simulation runs for agents with generic perception to converge to these stimulus values attributed generically to rival agents. A perception of low  $E$  in the rival agent might serve to focus the agent on attacking rather than searching for food since higher perceived  $E$  values are associated with less specific and more generic searching (via an increase in visual field size with the same discretization) which does not facilitate 'homing in' on rival agents. This suggests that in such a harsh environment it may not be useful to attempt to discern rival agent intentions but rather to focus unreservedly on the most vital behaviours according to given motivations. The less reactive behaviour of affect perceiving agents may be more appropriate in an environment that allows for numerous interactions and opportunities to obtain food resources but may be less productive in harsher environments where opportunities to find stimuli are reduced. In the summer-first condition in 10/50 cases generic perceivers dominate and evolve a generically attributed social stimulation value of 0.24 ( $\sigma = 0.12$ ). This tendency for generic perceivers to attribute a high degree of threat to rival agents in the summer-condition could owe to the higher frequency of agent interactions allowing for more opportunity to 'hit' or be hit.

### 3.4 Physiological Determinants of Death

From a physiological perspective, agents could die due to  $S$  excess, deficit or alternatively  $E$  deficit. In the summer-first condition, it was found that on average generic perceivers were more likely to die of  $S$  deficit and less likely to die of  $S$  excess than affect perceivers. In the winter-first condition, the opposite was found true.  $E$  deficit deaths were significantly higher in the winter-first condition and more likely to be suffered by affect perceiving agents in this case. In the summer-first condition  $E$  deficit deaths were rare for both types of perceivers.

### 3.5 Social Interaction

Agents in the summer-first condition generally attacked more, presumably as a consequence of being clustered around the densely distributed, numerous resources. Respective total hits (averaged over all runs) 45.9 ( $\sigma = 5.32$ ) and 40.63 ( $\sigma = 5.69$ ) for affect perceivers and generic perceivers after the summer of generation 1 were registered in this condition. This is considerably more than the 28.84 ( $\sigma = 5.33$ ) and 21.56 ( $\sigma = 4.31$ ) by the equivalent agents in the winter season of the first generation of the winter-first condition. The legacy of these contrasting hitting to

the two conditions. By the end of the first generation the respective average hitting totals stood at 61.16 ( $\sigma = 6.55$ ) and 56.38 ( $\sigma = 6.92$ ) compared to 42.88 ( $\sigma = 6.89$ ) and 37.68 ( $\sigma = 7.13$ ).

### 3.6 Emergence and Evolution of Display Strategies

Displays can be used to manipulate the behaviour of rival agents. To give an example, if an agent is perceived as being in  $S$  deficit and looking to attack then an affect perceiving agent in  $S$  excess is likely to escape on perceiving the threat. A 'trojan' display in this case might allow an agent to mask its true intentions since an evolved set of displays that leads to an increase of  $S$  display to 0.5 or above i.e. beyond the homeostatic, mid-point of the internal  $S$  value will fool affect perceivers into 'believing' that the threat is non-existent. This occurs since the rival would be perceived as being in  $S$  excess. This is important given that agent survival is contingent upon being able to hit other agents to avoid death from  $S$  deficit and being able to avoid being hit in order not to die from  $S$  excess.

A number of strategies were seen to emerge among individual agents and groups of agents for the various values associated with the presence of an agent or the presence of food and an agent. The focus of the following analysis was on the summer-first condition owing to the fact that generic perceiver agents dominated the winter-first condition whereas use of displays should be associated with agents able to perceive such displays.

Fig.3 and Fig.4 show an interesting example of possible emergent display strategies being used by agents in order to facilitate survival prospects. In this particular run, the overall number of survivors (35) at the last generation was the highest of all runs in the summer-first condition, and therefore represents an interesting case study. Survivors in this run were predominantly generic perceivers (33) as opposed to affect perceivers (2). In Fig.3 agents show, on average, a general inclination towards 'bluffing' when looking for food while both a rival agent and food resource is present. The effect momentarily drops around generation 25 but then increases rapidly up to the 30th generation. In general this might be a useful strategy to adopt if the displaying agent is not looking to attack since a depicted exaggerated threat will be more likely to 'frighten' off rivals. In Fig.4 agents show an increasing tendency to adopt an increasingly strong 'trojan' strategy while looking to attack in the presence of an agent. This again may be adaptive since an agent looking to attack could derive benefit from lulling the rival into a false sense of security through a display of non-aggression.

In order for such displays to be adaptive there would need to be agents capable of interpreting the displays i.e. affect perceiver agents. At an early stage in this run we see generic perceiver agents dominating the survivor rates and at a similar stage 'trojan' displays begin to evolve. It might be ex-

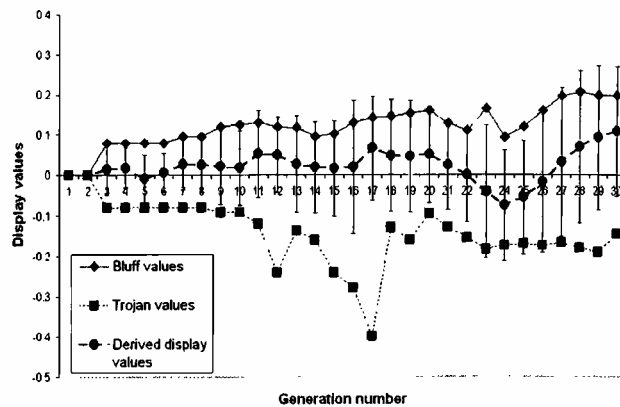


Figure 3: Graph showing average 'bluff' ( $W1$ ), 'trojan' ( $-W2$ ) and derived final display values when agent perceives agent and food and is currently *looking for food*, over 30 generations

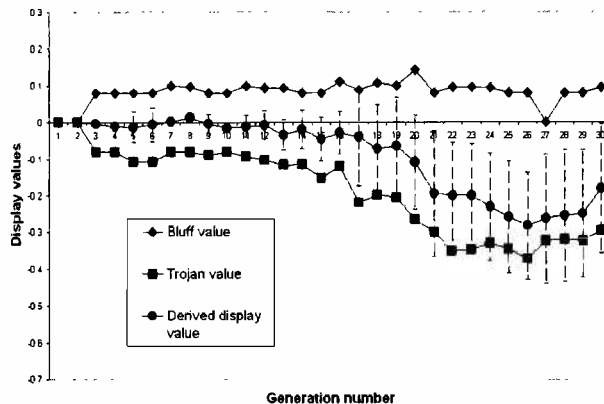


Figure 4: Graph showing average 'bluff' ( $W1$ ), 'trojan' ( $-W2$ ) and derived final display values when agent perceives agent only and is currently *looking to attack*, over 30 generations

pected that 'trojan' displays would evolve prior to the onset of generic perceiver agent domination and that such displays would be a cause of such survival success. Indeed, from generations 9 until 20 (during which time 'trojan' displays begin to evolve) affect perceiver agent survivors remain between 3 and 5. During the same period the ratio of 'trojan' to 'bluff' agents changes from 1:1 to 13:5. Could this strong effect just be an artefact of random drift? The highly evolved 'trojan' displays by generation 30 suggest otherwise. It is possible that such 'trojan' and 'bluff' strategies are effective even when affect perceivers are in a sufficiently large minority. Using 'trojan' or 'bluff' displays in the presence of such 'gullible' agents could entail a significant survival advantage and create evolutionary pressure to select for such a strategy. The fact that generic stimulus values did not stabilise at an early stage in the simulation run, together with the increasing evolutionary emphasis on 'trojan' display evolution from

generation 9 suggest that the number of affect perceivers extant in the environment in the early stages of the simulation run were sufficiently high from generation 9 to create an evolutionary pressure towards use of a 'trojan' display strategy.

A number of other examples of possible strategies emerging and evolving in summer-first simulation runs in which generic perceiver agents begin to dominate over evolutionary time occur. For example, a symmetric 'bluff' strategy to that mentioned above is in evidence in two runs. In other simulation runs, however, other apparent strategies emerge that appear to be highly contingent and context dependent. Over the 50 simulation runs, there was no consistent direction in which displays emerged and evolved but numerous instances of highly evolved 'trojan' or 'bluff' displays in different runs is indicative of evolutionary pressure that may have an adaptive end in such environments. These findings therefore support *hypothesis 2*.

#### 4 Concluding Remarks

A major benefit of using the game theoretic approach to studying signalling and behavioural interactions is that the rules established are simple, comprehensible and intuitively appealing; however, such theoretical models measure these benefits in a very abstract evolutionary setting. An ecological approach to the assessment of (pre)communicative behaviour, its underlying mechanisms and its connection to interaction over evolutionary time is always susceptible to problems of complexity. Reducing environments to their componential parts runs the risk that experiments and findings will be trivial but even slight increments to such complexity can lead to an exponential increase in analytical requirements. Therefore, a disciplined, systematic incremental approach that identifies the factors influencing the evolutionary trends and adaptive value of displaying and perceiving affective expression is necessary. The results of our experiments showed that perception of affect and use of displays can greatly influence survival prospects. Understanding the emergence and rationale of the rules that allow to categorise the ways in which such perception and expression are used and evolved is, hence, the aim of our approach.

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#### References

- [1] O Avila-García and L Cañamero. A comparison of behavior selection architectures using viability indicators. In *Intl. Wksp. Biologically-Inspired Robotics*, pages 86–93, 2002.
- [2] O Avila-García, L Cañamero, and R te Boekhorst. Analyzing the performance of winner-take-all and voting-based action selection policies within the two-resource problem. In *Advances in Artificial Life (Proc. European Conf. Artificial Life - ECAL '03)*, Springer LNAI vol. 2801, pages 733–741, 2003.
- [3] O Ávila-García, E Hafner, and L Cañamero. Relating behavior selection architectures to environmental complexity. In *From Animals to Animat (Proc. SAB'02)*, 2002.
- [4] R Aylett and L Cañamero, editors. *Animating Expressive Characters for Social Interactions (Proc. AISB'02 Symp.)*. Imperial College, London, UK, April 4–5, 2002.
- [5] C.L Breazeal. *Designing Sociable Robots*. MIT Press, 2002.
- [6] L Cañamero. Modelling motivations and emotions as a basis for intelligent behavior. In *Proc. First Intl. Conf. on Autonomous Agents*, pages 148–155, 1997.
- [7] T.H Clutton-Brock, F.E Guinness, and S.D Albon. *Red deer. Behaviour and ecology of two sexes*. Edinburgh University Press, 1982.
- [8] T.H Clutton-Brock and N McIntyre. *Red deer*. Colin Baxter Photography Ltd, Moray, 1999.
- [9] C Darwin. *The Expression of Emotions in Man and Animals*. Julian Friedmann Publ. London, second edition, 1979 [1872].
- [10] K Dautenhahn, A.H Bond, L Cañamero, and B Edmonds, editors. *Socially Intelligent Agents*. Kluwer, 2002.
- [11] R Dawkins. *The Selfish Gene*. Oxford University Press, second edition, 1989.
- [12] M Enquist. Communication during aggressive interaction with particular reference to variation in choice of behaviour. *Animal Behaviour*, 33:1152–1161, 1985.
- [13] M Enquist and P.L Hurd. Conventional signalling in aggressive interactions: the importance of temporal structure. *Journal of Theoretical Biology*, 192:197–211, 1998.
- [14] R.T Hanlon and J.B Messenger. *Cephalopod Behaviour*. Cambridge University Press, 1996.
- [15] M. D. Hauser. *The Evolution of Communication*. MIT Press, 2000.
- [16] P.L Hurd. Is signalling of fighting ability costlier for weaker individuals? *J. Theoretical Biology*, 184:83–88, 1997.
- [17] R Lowe and D Polani. Preventing bluff agent invasions in honest societies. In *Advances in Artificial Life (Proc. ECAL'03)*, Springer LNAI vol. 2801, pages 118–127, 2003.
- [18] D McFarland. Opportunity versus goals in robots, animals and people. In H.L Roitblat and J.-A Meyer, editors, *Comparative Approaches to Cognitive Science*, pages 415–433. MIT Press, 1993.
- [19] C.L Nehaniv. Meaning for observers and agents. In *IEEE International Symposium on Intelligent Control/Intelligent Systems and Semiotics*, pages 435–440, 1999.
- [20] J Noble. *The Evolution of Animal Communication Systems: Questions of Function Examined Through Simulations*. PhD thesis, COGS, University of Sussex, 1998.
- [21] J.A Russell and J.M Fernandez-Dols. *The Psychology of Facial Expression*. Cambridge University Press, 1997.
- [22] W.J Smith. *The Behavior of Communicating: An Ethological Approach*. Harvard, 1977.
- [23] N. Tinbergen. On aims and methods of ethology. *Zeitschrift für Tierpsychologie*, 20:410–433, 1963.