Social Adaptive Groups: A New Approach for Evolutionary Optimisation Based on Social Behaviour Evolution

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ABSTRACT
This paper describes a new approach for building evolutionary optimisation algorithms inspired by concepts borrowed from evolution of social behaviour. The proposed approach utilises a set of behaviours used as operators that work on a population of individuals. These behaviours are used and evolved by groups of individuals to enhance the group adaptation to the environment and to other groups as well. Each group has two sets of behaviours: one for intra-group interactions and one for inter-group interactions. These behaviours are evolved using mathematical models from the field of evolutionary game theory. This paper describes the proposed paradigm and starts studying its characteristics by building a new evolutionary algorithm and studying its behaviour.

Categories and Subject Descriptors
I.2.8 [Artificial Intelligence]: Problem Solving, Control Methods and Search—*Heuristic methods*

General Terms
Algorithms, Theory.

Keywords
Evolutionary Optimisation, Social Behaviour Evolution, Evolutionary Game Theory, Social Adaptive Groups.

1. INTRODUCTION
Nature has provided computer science with many sources of inspiration to develop a variety of optimisation approaches, of which natural selection or the Darwinian principle of "the survival of the fittest" has a lion's share. While many types of Evolutionary Algorithms (EAs) have been developed based on Darwin's theory and our modern knowledge of genetics, rarely if ever EAs, in their original form, have naturally shown the full range of properties exhibited by natural evolution. In particular, a varieties of extensions and modifications have been necessary in order to obtain EAs that could deal with multi-modal optimisation, multi-objective optimisation and dynamic optimisation problems.

In this paper we present a different approach to building EAs which can potentially deal with the problems mentioned above where populations show a natural tendency to maintain diversity and form groups. We take inspiration from the evolution of social behaviour. The proposed approach uses a notion of *fitness of groups* which takes different measures related to a group's survival and performance into account. Each group has a set of social behaviours (operators) that individuals use in interacting with other individuals from the same or different groups. The exact nature of such behaviours is determined by a probability distribution which is tuned by an evolutionary process so as to maximise group fitness. Each behaviour serves a specific purpose and contributes to a group's survival or to the group's interaction with other groups. The behaviour probability distributions of each group are updated dynamically during the optimisation process using a dynamic mathematical model from evolutionary game theory. In this paper, we use replicator dynamics model [2] to evolve the social behaviours of groups.

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2. PROPOSED APPROACH
In the real world, individuals affect each other's fitness value by social behaviours. These behaviours are used and evolved according to their impact on the collective performance, so the good behaviours will survive and be adopted, while bad behaviours will die away and disappear. Social interaction behaviours can be classified into four categories according to the change (increase or decrease) they cause to the fitness values of the initiator and the recipient. These four categories are: *altruism*, *spite*, *selfishness* and *cooperation* [1]. The pay-off of some behaviours is not immediate or direct to an individual's fitness. Instead, it may increase the *relative fitness* of the group in general, which in turn enhances the individual's fitness indirectly.

In the proposed paradigm, social behaviours are used as operators to move individuals in the search space, where individuals move and form groups as they socially interact. Social behaviours are dealt with as a trait of a group of individuals that describe the way individuals behave toward other individuals from the same or different groups. An appropriate representation for group behaviours is provided as well as an evolving mechanism.

The proposed evolutionary system can be described as a tuple $E = \langle X, G, V, B_{intra}, B_{inter} \rangle$ where $X = \{x_1, \dots, x_n \,|x_i \in R^{dim}\}$ represents a population of *n* real-valued individuals of length *dim*; G is the set of all possible groups, where $G \supset G_t = \{\, g_1, \dots, g_{N_t}\}$ represents the set of groups formed by individuals at time *t*; V is the group *behaviour probability distribution update function*; and, finally, B_{intra} and B_{inter} are two sets of transformations (operators) which represent the *intra-group* and *inter-group behaviours* used in pairwise interactions between individuals, respectively. The transformations are defined as follows:

$(x_i', x_j') = b(x_i, x_j)$, where $b \in B_{intra}$ or B_{inter}

where b is function that transform two individuals into two new individuals, as x_i interact with x_j. The behaviours cause to change the position of individuals in the search space. So, individuals move as they interact.

A group $g \in G_t$ is defined as $g = \langle M_t, \alpha_t, \beta_t \rangle$ where

$M_t = \{x_i, x_j \in X \,|S(x_i, x_j) \le \tau\}$, and

$\alpha_t \in R_+^{|B_{intra}|}$ and $\sum_{b \in B_{intra}} \alpha_t(b) = 1$

$\beta_t \in R_+^{|B_{inter}|}$ and $\sum_{b' \in B_{inter}} \beta_t(b') = 1$

The function S measures the similarity between a pair of individuals and τ is a threshold. In our initial implementation, we use the Euclidean distance as a similarity function (i.e., $S(x,y) = \sqrt{\sum_i (x_i - y_i)^2}$). The formation of groups is a dynamic process as individuals move freely around the search space as a result of interactions. α_t and β_t are probability distributions over B_{intra} and B_{inter} at time t, respectively, and $\alpha_t(b)$ denotes the probability of using behaviour b by the group g at time t. A function V *is* used to evolve behaviours. This is done by updating their probability distribution.

The process of evolving behaviours is based on assessing the effect of each behaviour on the group, and uses it to calculate the behaviour *pay-off,* $u(b) = F(g)e_{\theta_t}(b)$, where θ can be either α or β, $F(g)$ denotes a fitness function for groups, for $b \in B, e_{\theta_t}(b)$ represents the effect rate of behaviour b, where B= {*Cooperative, Selfish, Spiteful, Altruistic*} could be either B_{intra} or B_{inter}. The factors that should be included in calculating the fitness of a group must reflect different aspects of the group well-being and must not be based merely on the individual direct fitness values.

Intra-group behaviours deal with moving individuals within the area where the group resides, whereas inter-group behaviours move individuals across group areas. The intra-group behaviour directs individuals to the promising locations in the area occupied by a group, while, at the same time, exploring the surrounding areas and maintaining a good spread in the distribution of individuals. The inter-group behaviour, instead, moves individual between groups and also move individuals randomly to new spots in the fitness landscape to investigate the possibility of forming new groups there, in case the new area has enough resources to sustain a group.

The group fitness function is a linear combination of three values which represent three different aspects of group quality. Formally the group fitness is defined as follows:

$$F(g) = \frac{|G_t| - Rank(g)}{|G_t|} + SizeFitness\left(Size_g, \frac{|X|}{|G_t|}\right) + \frac{Volume_t}{\frac{Volume_{pop}}{|G_t|}}$$

where g is a group and $Rank(g)$ is a function that gives the ranking of g among other groups. For the purpose of ranking, groups are sorted in descending order. The sorting is based on the value of the expression *0.75*BestFitness+0.25*AverageFitness*. The top group's rank will be 0. The *SizeFitness* is as follows:

$$SizeFitness(S, Max_S) = \begin{cases} \frac{S}{Max_S} & if\ S < Max_S \\ 1 - \frac{S - Max_S}{Max_S} & otherwise \end{cases}$$

This function rewards groups with the "right size", bigger or smaller sizes leading to less group fitness. The volume of the group, $Volume_t$ is the volume of a *dim*-dimensional sphere, the radius of which is computed as one half the diameter of the group (i.e., the distance between the two individuals further apart in the group). $Volume_{pop}$ is the volume of the search space (typically a multi-dimensional box).

After a round of interactions, the procedure that evolves behaviours works out how each behaviour has influenced the relative fitness (group fitness), so we can apportion blame and credit. For intra-group behaviours of group g, the effect rate is computed as follows:

$$e_{\alpha_t}(b) = \frac{\omega_t(b)}{\Omega_t(g)}\left(w_1(b)\frac{Size_t - Size_{t-1}}{Size_{t-1}} + w_2(b)\frac{A_t - A_{t-1}}{A_{t-1}} + w_3(b)\frac{Volume_t - Volume_{t-1}}{Volume_{t-1}}\right)$$

where $b \in B_{intra}$, $\omega_t(b)$ is the number of occurrences of behaviour b and $\Omega_t(g)$ is the total number of behaviours that caused changes to the group, by interaction behaviours initiated by group members or by members of other groups. A_t is the average fitness of group members at time t.

The effect rates of inter-group behaviours B_{inter} are given by:

$$e_{\beta_t}(Cooperative) = 1 - \left|\frac{|G_t| - |G_{t-1}|}{|G_{t-1}|}\right| + 1 - \left|\frac{Size_t - Size_{t-1}}{Size_{t-1}}\right|$$
$$e_{\beta_t}(Selfish) = 1 - \left|\frac{|G_t| - |G_{t-1}|}{|G_{t-1}|}\right| + \frac{Size_t - Size_{t-1}}{Size_{t-1}}$$
$$e_{\beta_t}(Spiteful) = \frac{|G_t| - |G_{t-1}|}{|G_{t-1}|} - \frac{Size_t - Size_{t-1}}{Size_{t-1}}$$
$$e_{\beta_t}(Altruistic) = 1 - \left|\frac{|G_t| - |G_{t-1}|}{|G_{t-1}|}\right| - \frac{Size_t - Size_{t-1}}{Size_{t-1}}$$

After computing the effect rates and the group's fitness, we can update the behaviour distributions of the group and prepare for next round of interactions. The average of the pay-off of the two (intra- and inter-group) mixed behaviours is as follows:

$U(\alpha_t) = \sum_{b \in B_{intra}} u(b)\alpha_t(b)$ and $U(\beta_t) = \sum_{b \in B_{inter}} u(b)\beta_t(b)$

Then we use the *replicator equation* to find the new distributions of group behaviours. Namely,

$$\dot{\alpha}_t(b) = \alpha_t(b)\big(u(b) - U(\alpha_t)\big)$$
$$\alpha_{t+1}(b) = \dot{\alpha}_t(b) + \alpha_t(b) \text{ for } b \in B_{intra}$$
$$\dot{\beta}_t(b) = \beta_t(b)\big(u(b) - U(\beta_t)\big)$$
$$\beta_{t+1}(b) = \dot{\beta}_t(b) + \beta_t(b) \text{ for } b \in B_{inter}$$

More details on the proposed evolutionary system and some initial results can be found in [3].

3. FUTURE WORK

We plan to use the proposed approach on higher dimension problem and dynamic optimisation problems, and introduce the approach to a wider range of computational problem. We also plan to investigate using different model for behaviours evolving and using different measures for behaviour effects. Further features of groups related to increasing the perception of the group to the fitness landscape and enhancing the collective performance of the population, will also be studied and incorporated in the proposed model.

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