Fractals2019: Guiding Self-Organisation of Intelligent Agents

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Abstract. Fractals2019 is a new experimental entry in the RoboCup Soccer 2D Simulation League, based on Gliders2d, which extended agent2d code base. In developing Fractals we use elements of evolutionary computation, within the framework of Guided Self-Organisation. The evolution is guided by generic universal objective functions that relate information-processing and thermodynamic properties of collective action (i.e., collective distributed computation). Tactical tasks provide constraints on control parameters, varying which is the subject of the evolutionary process. Examples include evolving dash power rates, levels of pressing and risk-taking, as well as action evaluation weights, to optimise thermodynamic efficiency of collective behaviours, in addition to standard competition performance measures.

1 Introduction

The RoboCup Soccer 2D Simulation League continues to inspire fundamental research and development efforts in Artificial Intelligence, as well as general studies of complex systems and self-organisation. Simulated teams created over the years have demonstrated a number of advances in collective behaviour, which self-organises within a distributed environment of the RoboCup Soccer Simulator (RCSS), as a result of teamwork interactions and in response to opponents' actions [1–11].

Typically, self-organisation of complex behaviours is underpinned by low-level skills and dynamic world models of simulated autonomous agents, standardised over the years by several important base code releases. These include CMUnited team (USA) [12], UvA Trilearn" team (The Netherlands) [13], HELIOS team (Japan) [14], and MarliK team (Iran) [15]. In particular, we note the release in 2010 of the base code of HELIOS team, *agent2d-3.0.0*, later upgraded to agent2d-3.1.1. About 80% of the League's teams adopted agent2d as their base code, including our champion team, Gliders2016 [16, 11], which also utilised fragments of MarliK source code [15].

While developing Gliders, we augmented artificial evolution with human innovation, using Human-based Evolutionary Computation (HBEC) [17]. HBEC enabled optimisation of several components which we introduced and investigated between 2012 and 2016: an action-dependent evaluation function [18], a particle-swarm based self-localisation method and tactical interaction networks [19–22], dynamic tactics with Voronoi diagrams [23], bio-inspired flocking behaviour [24], and diversified opponent modelling [16].

The main factor which allowed Gliders to demonstrate a high tactical proficiency was the increased mobility of players, resulting in a better control over the field. Recently, we released the code base *Gliders2d* [25], version v1, with six sequential changes, from v1.1 to v1.6, mapping to six evolutionary HBEC steps (version Gliders2d-v1.0 is identical to agent2d-3.1.1). In that release we traced improvements in the team performance, with respect to the achieved goal difference and attained points, along the following steps:

- Gliders2d-v1.1: stamina management with higher dash power rates (less conservative usage of the available stamina balance; `strategy.cpp`);
- Gliders2d-v1.2: pressing behaviour (more intense pressing of the opponents in possession of the ball; `bhv_basic_move.cpp`);
- Gliders2d-v1.3: action-dependent evaluator (selecting more diversified actions aiming to stretch the opposition most; `sample_field_evaluator.cpp`);
- Gliders2d-v1.4: positioning of attacking players using Voronoi diagrams (maximising the potential of ball reachability; `strategy.cpp`);
- Gliders2d-v1.5: defensive formations (positioning defenders and midfielders closer to own goal; `*.conf`);
- Gliders2d-v1.6: modelling risk in intercept behaviours (enabling risky passes in specific situations; `strict_check_pass_generator.cpp`).

As noted in [25], Gliders2d is a separate evolutionary branch, different from the (Gliders2012 — Gliders2016) branch, and hence, Gliders2d-v1.6 is not a subset of any of Gliders2012 — Gliders2016 teams, although it approaches the strength of Gliders2013 [19].

Fractals2019 is a new team which is partially based on Gliders2d, while retaining some elements of the champion team Gliders2016. To a large extent, Fractals2019 is an experimental entry, motivated by a new set of aims. Specifically, we intend to redefine the fitness landscape used by evolutionary computation in terms of universal objective functions, rather than in terms of the performance metrics alone. Our overall approach attempts to achieve *guided self-organisation* of tactical behaviour, as described in the next section.

2 Methodology: designing thermodynamically efficient behaviours

Typically, self-organisation is defined as the evolution of a system into an organised form and/or functionality in the absence of external pressures. Guided Self-Organisation (GSO) integrates two alternatives: (i) the process of self-organisation which explores the available search space (implying autonomy), and (ii) the process of designing a desirable outcome by providing a "blueprint" (implying control) [26]. The GSO framework has been applied to several robotic scenarios, where such an integration is proposed by (i) setting task-independent universal objective functions, while (ii) placing task-dependent constraints and feedbacks on the system dynamics, so that the combination implicitly guides the resultant behaviors and interactions towards the desirable outcomes [27–35].

During self-organisation within a system, interactions among the system's elements produce a spontaneous increase in order. On one hand, in terms of distributed computation, the system increases its information-processing capabilities [36, 37, 21], manifested in statistical regularities that can be observed and measured information-theoretically [38–42]. On the other hand, in terms of thermodynamics, this increase must be balanced by entropy production, exported to the system's exterior [43–47].

In the Fractals branch we identify several important *control* parameters, varying which allows us to measure the universal fitness levels via *order* parameters. Among the control parameters which prominently feature in Gliders2d-v1.6 we note: dash power rates used in stamina management; level of pressing (more precisely, pressure) applied to the opponents in proximity to the ball; weight factor(s) scaling the action evaluation, as well as players positioning, towards different sectors of the field; and level of risk taken in considering passes. Of course, other rates and factors can be added: the important point is that these control parameters must affect the global team behaviour, and have a sufficiently broad (preferably, continuous) range, within which they may make a transition through a critical point, separating phases with different energy profiles. Considering the corresponding energy behaviour and the overall thermodynamics is crucial to the analysis of phase transitions, and so we focus on how our control parameters affect the thermodynamic balance in Fractals. In general, the control parameters may be further constrained dependent on a specific task (e.g., defensive play, offside trap, free-kicks, and so on).

On the other hand, the order parameters are chosen to represent task-independent objectives: maximisation of spatiotemporal coordination [28, 29], maximisation of information flows [22, 42], maximisation of thermodynamic efficiency [47], etc. In particular, we focus on thermodynamic efficiency of collective computation defined, for a given value of the control parameter, as the ratio of the generated order (i.e., the reduction of uncertainty, measured as Shannon information) to the required thermodynamic work. The latter is closely related to the sensitivity of collective computation, measured as Fisher information [47]. For example, the collective motion (which is a result of distributed computation) may undergo a transition from a disordered to a coherent phase in response to changes in the number of nearest neighbours affecting an individual's alignment. The reduction in uncertainty (derivative of Shannon information) and the cumulative sensitivity (integrated Fisher information) are balanced in both disordered and coherent phases, so that their ratio, i.e., the thermodynamic efficiency, is steady. However, during a kinetic phase transition, or in other words, at the critical point, this balance is broken and the thermodynamic efficiency abruptly increases.

Evolving control parameters to critical points, where the order parameters approach the "edge of chaos", is the main goal of the Fractals team, designed within a GSO framework. Our conjecture is that at such critical regimes the resultant tactical behaviour is the most complex and diverse, and therefore, the most challenging for the opponents. In other words, we aim to evolve the behaviours that maximise the thermodynamic efficiency of collective computation underlying the teamwork.

3 Conclusions

Team Fractals2019 is based on recently released Gliders2d code base [25], built up on agent2d-3.1.1 [14]. Its development follows the methodology of Guided Self-Organisation in an attempt to evolve strong tactical performance, described by universal objective functions and restricted by task-dependent constraints. The primary universal objective that we consider is the thermodynamic efficiency of collective action, where the latter is seen, in the most generic sense, as collective distributed computation. For a specific value of a control parameter (e.g., dash power rate, risk level, and so on), the thermodynamic efficiency relates the reduction of uncertainty, measured by changes in Shannon information, to the expenditure of thermodynamic work, measured by integrated Fisher information [47]. Fractals2019 is an experimental entry aimed to verify the extent of applicability of the GSO approach, set specifically in terms of contrasting information-processing and thermodynamic factors, to RoboCup simulation.

4 Acknowledgments

We thank David Budden for developing a new self-localisation method introduced in Gliders2013 [20, 19] and Oliver Cliff for developing a new communication scheme adopted by Gliders from 2014 [23]. We are grateful to Gliders team members: Oliver Obst, particularly for establishing the tournament infrastructure supporting the team's performance evaluation on CSIRO Accelerator Cluster (Bragg) in 2012–2013, and Victor Jauregui, for several important insights on soccer tactics used in Gliders2016 [16].

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