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An information-based adaptive strategy for resource exploitation in competitive scenarios

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ABSTRACT

Given an exploitation problem, in which a number of agents compete for a limited renewable resource, the optimal harvesting strategy depends on the ratio between resource availability and exploitation effort. For scarce resource a purely competitive, greedy strategy outperforms a more collaborative approach based on the Collective Intelligence, while for more abundant resource the opposite holds. The rationale for this behaviour lies in the amount of information each strategy is able to provide and a combined strategy is possible according to which agents choose dynamically the most informative strategy according to a minimum entropy criterion. This approach, which provides best performance for both under and over-exploited scenarios, can be used to monitor the resource status for management purposes and is effective in both centralised and decentralised decision making.

1. Introduction

Several natural phenomena can be cast within the framework of competition: living beings compete for survival, species compete for niches, humans compete for financial resources and, adventuring ourselves into more questionable conjectures, cultures compete for supremacy, ideas compete for our attention [1], and natural selection is even suggested to operate in the cosmos [2]. These ideas are linked to different versions of Darwinism: *best competitors will survive* and thus dominate in the long run. Competition is thus linked to the concept of optimisation: via competition agents will 'improve' at required tasks.

This framework is intuitively appealing, so much so that it can be easily exported to man-made problems and in particular to engineering and numerical optimisation. Either explicitly, as in the case of Evolutionary Computation and Particle Swarm Optimisation or implicitly, as in standard gradient-based techniques, many methods employed for computer-driven optimisation rely on some sort of competition between components of the optimisation algorithms.

However, competition can express itself at different levels: a short-term winning strategy may fail in the long-term and a locally winning strategy may fail globally. Optimisation practitioners are well aware of these problems, which manifest themselves in the challenge in finding global solutions among local ones.

When the process to optimise can itself respond to the optimisation and adapt to it, the dynamics can be even more complex, in which case modelling may be the only avenue for us to unravel, predict or control the process under analysis.

In recent years we studied one such system. We modelled a fishery including fishing vessels harvesting several fishing zones of constant resources [3]. Vessels compete by aiming at under-exploited areas, whereby avoiding sharing the limited resource with the majority of other vessels. This is an example of a Minority Game [3,4] and in the Game Theory literature it is known that this apparently simple process can generate complex dynamics. Next, we included a resource dynamics by simulating population growth in the target species [5,6]; this imposed on the vessels the additional complication of accounting for the evolution of the resource abundance in response to fishing. Finally, we included fleet managers and resource managers, who can impose

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constraints of the fishery either by regulation [6] or by centralised fleet control [7]. Each step increased considerably the overall complexity of the problem.

For each scenario, we studied how different fishing strategies perform both in a single strategy setting (in which all vessels in the fleet adopt the same strategy) and in an evolutionary economic setting (in which strategies spread in the population according to their past performance). Of particular interest is the comparison between the following strategies: a purely competitive approach, which we call MG in this paper (since this is the strategy normally adopted in Minority Game studies), in which agents aim to optimise their individual return, and a more collaborative approach, called Collective Intelligence (Coin in the rest of the paper), in which agents try to optimise their *impact* on the fleet return. It seems reasonable to consider MG as the 'null hypothesis' against which we test the Coin performance.

One of the most important results of our previous work is that the effectiveness of Coin depends on the ratio between available resource and fishing effort. In particular, the transition from Coin to MG dominance in the fishing fleet coincides with the transition from under-exploited to over-exploited resource status (in this paper the level of exploitation is operatively defined as the ratio between available resource and harvesting potential. Other definitions, accounting explicitly for resource dynamics and other ecological factors, could also be employed, but would make the interpretation of the modelling results less straightforward.). In [5] we have speculated that this transition could, in principle, be used by a resource manager to detect the level of resource exploitation and decide on possible intervention. The purpose of this work is to explore this idea further and discuss some steps towards a possible implementation.

We start by setting the problem and describing the Coin approach. We then summarise the results from our previous work most relevant to this paper and analyse our new results. We conclude with a discussion of the possible future development of this research.

2. The model

In this paper we report on a model of a simplified, non-spatially explicit fishery, although the model could easily be extended to the exploitation of other renewable resources. We imagine N fishing vessels $n=1\ldots N$ and Z fishing zones in which an amount Fish_z, $z=1\ldots Z$ of resource is available. The vessels do not have information about the global distribution of Fish_z and decide where to direct their effort according to the discounted returns of their past catches in the different fishing zones (see [3] for details).

Each vessel has a maximum allowed quota (which alternatively can be interpreted as a limited fishing capacity). At each fishing period, a vessel targets a single fishing zone and the resource available in that zone is shared equally among all vessels targeting it. Thus, the catch of a vessel n is given by

$$Catch_n = Min\left(Fish_{\mathrm{zone}_n} / Fleet_{\mathrm{zone}_n}, Quota\right) \tag{1}$$

where Catch_n is the amount of fish caught by vessel n, zone_n is the fishing zone chosen by vessel n, $\mathrm{Fish}_{\mathrm{zone}n}$ is the amount of fish available in zone_n, $\mathrm{Fleet}_{\mathrm{zone}}$ is the number of vessels which chose to fish in zone_n, with which vessel n has to share the available resource. We do not model fishing costs (navigating to the zones, equipment renting/buying, etc) though these could easily be included if needed.

The total catch of the fleet is obviously given by the sum of each vessel's catch,

$$TotalCatch = \sum_n Catch_n \tag{2}$$

The maximum possible catch of the entire fleet is given by either the total amount of resource in the fishery or the sum of the maximum allowed quota per vessel, if the resource is abundant:

$$MaxCatch_{Fleet} = Min\left(\sum_z \mathrm{Fish}_z, N * Quota\right) \tag{3}$$

Notice that, because each vessel has a maximum allowed quota, we have:

$$TotalCatch \leq MaxCatch_{Fleet} \tag{4}$$

that is, unless the vessels spread their effort wisely, the fleet may not be able to catch to its full capacity.

3. The Minority Game

Given a resource distributed over different zones and a number of vessels with the same fishing capability, we expect that the vessels which access the least-exploited zones will face less competition and thus share the local resources with the least number of competitors, catch the most fish and consequently perform the best. Basically the problem can be cast within a game-theoretical framework, in which agents aim to predict which areas will be least exploited at the next iteration. This is a generalised version of what is called a Minority Game in the Econophysics literature [3,4] (see also *http://www.unifr.ch/econophysics/minority/*).