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ANALYSIS

Improving resource exploitation via collective intelligence by assessing agents' impact on the community outcome

*Fabio Boschetti**

CSIRO CMAR, Australia

A R T I C L E I N F O

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A B S T R A C T

A Collective Intelligence (COIN) can improve the exploitation of a limited renewable resource compared to fully cooperative or fully competitive approaches. The main strength of a COIN lies in approximating the impact of an agent on the short-term behaviour of a Complex Adaptive System. By penalising behaviours which lead to no measurable impact, COIN simplifies the implementation of an appropriate cost function which each agent needs to optimize in order to reach a global, community-wide goal. On a number of virtual experiments mimicking a fishing fleet operating in areas of different fishing capacity, a COIN provides optimal catches for the fleet while at the same time each individual vessel also maximizes its own profit: no individual sacrifice is required to achieve the common goal. In the view of possible application by real human agents, I propose a simplified implementation of a COIN, which involves only elementary numerical operations and minimum bookkeeping and can thereby be carried out simply by 'pen and paper', with no help of electronic devices.

1. Introduction

In a world of limited resources and ever expanding demands, the contribution that scientific research can offer to resource exploitation and management is not limited to the study of the dynamics of the resource itself, but, at least as important, includes understanding how humans interact with the resource and compete to access it. Today, for a large section of the scientific community, understanding and modelling are synonymous; it is via comparing modelling results to reality that we check whether our assumptions about a problem are correct. A 'good' model, which includes satisfactory approximation of main factors, dynamics and causal relations, encloses our understanding of a problem and our (currently best) hope for prediction. Within the framework of natural resource exploitation, this implies that we need to model the drivers which lead humans towards a resource, the way they compete, the way they obtain and process information about the resource and eventually the way they take decisions on how to act upon it. I address this problem by simplifying and porting to ecological modelling ideas taken from the Collective Intelligence literature (Wolpert and Tumer, 1999) and linking them to more established agent-based and game theoretical tools.

The Collective Intelligence (COIN) main strength lies in approximating the impact of an agent's action on the dynamics of the overall population. This may be more or less difficult depending on the management style. Under a strong top-down management scenario, simulating a community of agents is fairly simple, since the action of each agent is strongly rule-based and thus fairly predictable. If however the management style allows for competition and adaptation, then the agents' behaviour is far less constrained and the resulting dynamics much more complicated. In this

* Tel.: +61 8 9333 6563.
E-mail address: fabio.boschetti@csiro.au

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scenario, local interactions among agents may result in large scale community-wide behaviour whose dynamics is difficult to predict (at least without modelling) from the knowledge of each agent's action. The arising of large scale dynamics from fundamentally different small scale dynamics is often defined as emergence[1] (Boschetti et al., 2005). Emergence is thus crucial to both the manager and the agent; the manager needs to 'engineer' policies in order to achieve resource-wide or community-wide outcomes with the understanding that the relation between the policies (which act at the small scale of the agent) and the aimed outcomes (at the scale of a community and resource) is not trivial. Each agent also needs to understand this emergent process in order to choose how, where and when is best to access a resource, depending on the behaviour of the other agents and the resource itself. Thus, the question of how an agent's action affects the community behaviour is crucial to both the manager and the agent. Here is where COIN plays a role.

COIN's crucial insight lies in discriminating between the agent's *contribution* to the community outcome and its *impact* on it. Here the contribution is the part the agent plays in the final outcome. The impact is how the agent directly affects the outcome or, said differently, what the outcome would be without the agent's intervention. An example clarifies the difference. Two agents, Paul and Mary, wish to collect apples from an orchard. Each can carry at most 2 bags of apples, one per hand. In the first scenario the orchard produces 2 bags of apples. Paul and Mary collect one bag each. Paul contribution is one bag. His impact however is zero, since had Paul not been there, Mary would have been able to collect both bags. In the second scenario the orchard produces 4 bags of apples. Now Paul and Mary collect two bags each. Paul's contribution is two bags. His impact now is also 2 bags, since had Paul not been there, Mary would have been able to carry only 2 bags, and 2 bags would have been left uncollected.

Previous work in COIN (Wolpert et al., 2000; Wolpert and Tumer, 2001) shows that the apparently minor difference between contribution and impact plays a major role in simplifying optimization problems in which agents need to take local decisions in order to solve a global problem. This is particularly relevant to this work since the management of a limited resource can indeed be seen as an optimization problem in which the manager aims to optimize (or at least improve) global exploitation and sustainability and the agents aim to optimize (or at least improve) their local return and long-term gain. A vast literature (Hardin, 1968; Batten, in press) and an even vaster set of real world examples suggest that these two aims are in direct conflict: the selfish (local) interest of each agent often goes against the public (global) good.

The main result in this work is to show that this is not necessarily the case if the difference between *contribution* and *impact* is accounted for; via modelling a fishery exploitation problem, I show that the use of COIN leads to improved resource exploitation not only for the overall community but *also for each individual* (on average); that is, no personal sacrifice is required for the good of the community. This has the potential to offer a radical shift in the way communal resources are managed and is worth an in-depth investigation, of which this work represents a first step.

Apart for porting COIN to ecological modelling, this work provides two further contributions. First, despite the simplicity of the underlying idea, COIN literature is fairly cryptic and rich of terminology not easily accessible to ecological modellers; here I strive to describe the COIN algorithm in the simplest possible fashion. Second, COIN was not designed with human agents in mind; I present a simplified COIN which could potentially be employed by real people with *no need of computer aid*, by simply performing elementary calculation with pen and paper. The results could naturally be extended to the exploitation of resources other than fisheries.

The paper is organised in the following way. First, I cast the management of a limited renewable resource within a game theoretical framework by describing the Minority Game and its self-referential and self-defeating nature. I then describe the agent-based model employed and how this can simulate four different virtual fishing fleets; a fully competitive one, a fully cooperative one, one which follows COIN ideas and one which takes fully random actions. After testing the four approaches on a number of fishing scenarios, I conclude by discussing the current limitations of the method and some directions for future study.

2. Competition for limited resources in the virtual fishery — the minority game

In the last few years a considerable body of work has been published on the study of the Minority Game (Zhang, 1998; see also the pioneering work by Arthur (1994) on the related El Farol Bar Problem and http://www.unifr.ch/econophysics/minority/ for an exhaustive collection of papers on the subject). Despite employing largely unrealistic simplifications in the behaviour of the agents, this tool has allowed scientists (mostly physicists) to highlight the unexpected and often counterintuitive dynamics displayed by the community of competitive agents as a whole, and how this changes dramatically as a function of the agents' behaviours (Savit et al., 1999).

The fundamental reason for the complexity of the Minority Game (and of the competition for limited resource in general) is its self-referential and self-defeating nature (Batten, in press; Batten and Boschetti, in press). Imagine a group of individuals who routinely choose where to access a limited resource. The amount of the resource an individual can obtain depends on how many other individuals choose to access the resource at the same location (since the resource is limited and needs to be shared). How many individuals choose a specific location depends in turn on the expectation that the location will be more or less exploited. Such expectation will guide the individuals' choice and consequently its final level of exploitation. Consequently, the expectation actually determines the outcome: this is the self-referential aspect. Also, the more people expect a location to be profitable, the more people will access it and the less profitable the location will result (since too many individuals have to share the limited

[1] Emergence is a hardly debated term in the physical and philosophical community. In this work I use it in the weak sense described in the text (see also Bedau, 1997).