Theory of Social Networks Applied to an Evolutionary Minority Game: an Agent Based Model in Swarm

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[EXTENDED ABSTRACT]

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Introduction

Game Theory is a distinct and interdisciplinary approach to the study of strategic behaviour. The disciplines most involved in game theory are mathematics, economics and the other social and behavioural sciences. Game theory (like computational theory and so many other contributions) was founded by the great mathematician John von Neumann.

The Minority Game (MG) is a simple, generalized framework, belonging to the Game Theory field, which represents the collective behaviour of agents in an idealized situation where they have to compete through adaptation for some finite resource.

While the MG is born as the mathematical formulation of "El Farol Bar" problem considered by Arthur (1994), it goes way beyond this one, since it generalizes the study of how many individuals may reach a collective solution to a problem under adaptation of each one's expectations about the future. In Arthur (1994) the "El Farol Bar" problem was posed as an example of inductive reasoning in scenarios of bounded rationality. The olympic rationality which is usually assumed in economics – perfect, logical, deductive rationality – is extremely useful in generating solutions to theoretical problems, but it fails to account for situations in which our rationality is bounded (because agents can not cope with the complexity of the situation) or when ignorance about other agents ability and willingness to apply perfect rationally lead to subjective beliefs about the situation. Even in those situations, agents are not completely irrational: they adjust their behaviour based on what they think other agents are going to do, and these expectations are generated endogenously by information about what other agents have done in the past. On the basis of these expectations, the agent takes an action, which in turn becomes a precedent that influences the future behaviour of agents. This creates a feedback loop: expectations arise from precedents and then create the actions which, in turn, constitute the precedents for the next step.

The original formulation of "El Farol Bar" problem is as follows: N people, at every step, take an individual decision among two possibilities. Number one is to stay at home; number two is to go to a bar. Since the space in the bar is limited (finite resource), the time there is enjoyable if and only if the number of the people there is less than a fixed threshold (aN, where $a<1$). Every agent has his own expectation on the number of people in the bar, and according to his forecast decides whether to go or not. The only information available to the agents is the number of people attending the bar in the recent past; this means that there is no deductively rational solution to this problem, but there can be plenty of models trying to infer the future number according to the past ones.

The other very interesting aspect of the problem is that if most agents think that the number of people going to the bar is > aN then they won't go, thus invalidating their own prevision. Computer simulations of this model shows that the attendance fluctuates around aN in a (aN,(1 - a)N) structure of people attending/not attending. The "El Farol Bar" problem has been applied to some proto-market models: at each time step agents can buy (go to the bar) or sell an asset and after each time step, the price of the asset is determined by a simple supply-demand rule.

The MG has been first described in (Challet and Zhang, 1997) as a mathematical formalization and generalization of "El Farol Bar" problem. It is assumed that an odd number of players take a decision at each step of the simulation; the agents that take the minority decision win, while the others loose. Stepping back to "El Farol Bar" problem, we can see it as a minority game with two possible actions: a1 = 1 (to go to the bar) and a2 = -1 (not to go to the bar). After each round, the cumulative action value A(t) is calculated as the sum of each value given to the single actions. The minority rule sets the comfort level at A(t) = 0, so that agent is given a payoff -ai(t)g[A(t)] at each time step with g an odd function of A(t).

Introducing communication among agents

In Remondino (2004) and in Remondino and Cappellini (2005) the idea of introducing a social network among agents playing a Minority Game was explored to demonstrate that an agent based simulation could prove a "rule of thumb", i.e.: the more the relations among the agents, the higher the chance for the agents to change their minds.
In this work, instead, we examine the introduction of a social network in the same context, but from a very different point of view; now we use network theory and we refer to the "Small Worlds" phenomenon to make more realistic the way the agents are connected among them. In a social network, individuals are represented, conceptually and graphically, as the nodes of a networks formed by the subjects themselves and the relationships connecting them. The distance between two individuals is measured in terms of the number of links that eventually connect them indirectly. This kind of distance is defined "degree of separation". In the sixties, Stanley Milgram showed empirically that the distance between two randomly chosen individuals is not longer than six passages. Those experiments are part of the researches on the Small Worlds phenomenon, so called for the saying that recurs when we meet a stranger and we discover some common acquaintance. In order to formalize mathematically the Small Worlds phenomenon we refer to the "Beta Model" by Watts (1998). In our Minority Game, the players are connected in a social network defined by the Beta Model.

Agent Based Simulation

According to (Gilbert, Terna 2000):

"The logic of developing models using computer simulation is not very different from the logic used for the more familiar statistical models. In either case, there is some phenomenon that the researchers want to understand better, that is the target, and so a model is built, through a theoretically motivated process of abstraction. The model can be a set of mathematical equations, a statistical equation, such as a regression equation, or a computer program. The behaviour of the

model is then observed, and compared with observations of the real world; this is used as evidence in favour of the validity of the model or its rejection"

Computer programs can be used to model either quantitative theories or qualitative ones; simulation has been successfully applied to many fields, and in particular to social sciences, where it allows to verify theories and create virtual societies. In order to simulate the described problem, multi-agent technique is used. Agent Based Modelling is the most interesting and advanced approach for simulating a complex system: in a social context, the single parts and the whole are often very hard to describe in detail. Besides, there are agent based formalisms which allow to study the emergency of social behaviour with the creation and study of models, known as artificial societies. Thanks to the ever increasing computational power, it's been possible to use such models to create software, based on intelligent agents, which aggregate behaviour is complex and difficult to predict, and can be used in open and distributed systems. The concept of Multi Agent System for social simulations is thus introduced: the single agents have a very simple structure. Only few details and actions are described for the entities: the behaviour of the whole system is a consequence of those of the single agents, but it's not only the sum of them.

In our simulation model of MG we used the Agent Based paradigm and, from a technical point of view, we decided to implement it using Swarm in Java. The software, the source code of the simulation model and the instructions on how to use it are available at http://eco83.econ.unito.it/dottorato/marco_lamieri/evolutiveMG

Genetic Algorithms and Classifier Systems in the Model

In the classic MG model the agents define their behaviour from a series of rules whose relative importance in the decision process evolves according to the correctness of each rule in the recent past, and the agent chooses as its own mental model the rule which, till then, proved to be the best one.

In our simulation of MG we used evolutionary algorithms to model the agents' decision process. Evolutionary algorithms are used in the simulation with a "mind-like" focus, i.e.: they define the mind of the agents along with the other rules. This has been carried on at two different levels:

1) genetic algorithms and classifier systems have been used as one of the rules that the agents know and use to draw their forecasts about the next decision step;
2) classifier systems have been used to interpret the information that each agent gets from the others with which she is linked through the communication network.

At the first level genetic algorithms and classifier systems are used as optimizing techniques in order to figure out the best strategy for future actions based on the knowledge of past action's outcomes.

At the second level the classifier system is used to interpret the information coming from communication among agents. The classifier's 'condition' part contains the decisions taken by the neighbours, while the classifier's 'action' part is the choice the agent will make in the next turn. Using this mechanism each agent learns how to react to the stimuli coming from the environment – constituted by the messages coming from other entities linked in the network – in a limited rationality context, since it doesn't know the choices of all the agents in the model, but only those of the agents directly linked with it. In this way the classifier system becomes realistic as decision process model because it infers in an inductive way the system's dynamic, by knowing just a part of the whole system.

These algorithms have been implemented in the simulation using ART library - Artificial Reasoning Toolkit (http://artlibrary.sourceforge.net/) by M. Lamieri e G. Ferraris.

Conclusion

We built a Minority Game model in Swarm, with the innovation of a social network linking the agents involved, using a Small Worlds graph. Besides we introduced genetic algorithms and classifier systems to model the agents' minds and they adaptive behaviour.
The results are quite interesting; we observed how the communication adds information to the agent and how the effects are correlated with the form of the network used; if the network has many links, the communication stabilizes the system and reduces the variance. A network with less links – but always featuring Small Worlds properties – can give better results and reduce the fluctuation around the equilibrium point only if particular rules of communication are introduced. In some cases we observed cyclic behaviours of the system, due to the communication. The use of evolutionary algorithms as a decision rule allows us to evaluate the agents' cognitive process, by observing how these rules require a long tuning period to give good results in this context.

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