Report on accomplished research

Stefano Battiston
Laboratoire de Physique Statistique ENS, 24 rue Lhomond, 75005 Paris FRANCE
(Dated: January 10th 2004)

In my PhD thesis work I have studied the **network of corporate boards and directors**, and the **network of firm ownership** in the stock market, two socio-economical networks with a very high impact from the point of view of global economic strategy and global capital control. These networks display very non trivial structures. The statistical physics approach consists in trying to relate the macroscopical properties of a system to the local processes taking place on the nodes and the links of the network. I have investigated how the structure of the corporate directors network can influence the decision making process in which they are involved. I have introduced "smart" measures of local connectivity, which allow to extract the backbone of the ownership networks.

My previous research activity was in Computational Neuroscience. I have studied on several neurobiological substrates the way the information about a stimulus is encoded by the system. I have also developed a method to classify semi-automatically the action potential in neural recordings.

All my publications and research paper are available at http://www.lps.ens.fr/ battiston/

I. THE PHD THESIS WORK

The **board network** consist of boards connected through common directors. The **director network** is the network obtained taking the directors as nodes, and a membership in the same board as a link. It is well known that the director network of the largest companies in the US and in other countries has a high degree of **interlock**, meaning the fact that some directors serve on several boards at the same time, so that many boards are connected by shared directors. Interlock convey information and power.

Stocks and shareholders can be represented as vertices connected by *weighted* links corresponding to shareholding relationships. In this framework, the in-degree k_{in} of an investor corresponds to the number of assets held (***portfolio diversification***), while the weights of the incoming links determine (along with the market value of the stocks) the invested wealth v of the the investor (***portfolio volume***).

What emerges from the study at the level of the topological properties is the high heterogeneity of these networks, which prevent from giving a satisfactory description in terms of simple average quantities. While a random graph or a lattice can be very well described in terms of its average connectivity, here highly connected nodes can play a very important role even if there is just a few of them.

The approach of statistical physics consists in trying to relate the macroscopical properties of a system to the local processes that take place on the nodes and the links of the network. An important lesson from statistical physics is that an heterogeneous topology can change completely the behavior of a dynamical process taking place on a network. We might then expect the topology of social networks to play a role in a decision making process and the topology of the ownership network to a play a role in the propagation of financial control and instabilities.

The thesis work has been supervised by **Gérard Weisbuch** at the **Ecole Normale Supérieure** and it has been done in collaboration with Eric Bonabeau (**Icosystems**, Cambridge, US) and Guido Caldarelli, Diego Garlaschelli and Michele Catanzaro (**Univ. La Sapienza**, Rome). Icosystems is a consulting firm specialized in complex system solution for business and management. The research group of Guido Caldarelli is part of the european project **COSIN** (www.cosin.org), coordinated by Guido Caldarelli and funded by the **Future and Emerging Technologies** department of the Information Society Technology Program.

The main results obtained in my thesis are the following.

A. Interlock structure and Decision making Dynamics

We have introduced a simple model in which it makes sense to ask and in which we are able to answer two fundamental questions:
1. can a minority of well connected directors (a "lobby") drive the decision of the majority of a board?
2. under which conditions a large majority of boards making a same decision can emerge in the network?

We have introduced a quantity that predict the impact of the lobby on the decision made by the whole board, this quantity being based on the structure of the lobby. Moreover, looking at the data, we find that in a significant fraction of real-world boards there is powerful lobby.

We have extended our model to include cross-boards influence. We have shown that if directors with appointments in several boards influence the decision only with their opinion, this has little effect. If, by contrast, they make everybody in the board know what other connected boards have decided, then all boards rapidly converge to the same decision.

Results are published in [4,5,7] (see publication list). The article [4] has been commented on Nature News , witnessing the interest for a wider public of such kind of questions (see http://www.lps.ens.fr/ battiston/)

B. Capital control networks

In our network representation of the stock market, the portfolio diversification and the wealth invested by shareholders are related to the connectivity of the nodes and to the weights of the links.

While a large number of factors determines the choice of investors in building up their portfolio, making it very hard to provide a realistic model, surprisingly, clear trends emerge at the statistical level. We have found that the portfolio diversification and the invested volume display a neat power law distribution. Moreover the portfolio diversification scales as a power-law function of the invested volume. These findings are in contradiction with classical portfolio theories and ask for an explanation in terms of economical behavior of the investors.

We have proposed a simple mechanism of network formation that reproduces such scaling invariance, a property that appear to be common in the stock markets we have analyzed.

The weighted nature of the links plays here a crucial role. We have introduced quantities that are analogous to in-degree and out-degree but that take into account the relative importance of shareholders, setting a framework that has allowed us to ask and answer the following questions:
1. how small is the subset of "super-investors" that controls the major part of a market
2. how such "super-investors" share out the market among themselves (whether each one controls different companies or if instead they control the same companies)

The three markets under study have revealed to have different structures: the Italian market is dominated by a subset of holders representing 10% of all holders in the data, and they share out the market in disconnected parts.

By contrast, in the US market the super holders are 1% of the total and they share the same pool of stocks.

Results are reported in [6][8][9] (see publication list).

C. Differential Games on Networks

During the thesis we have also explored a more theoretical direction, in particular we have tried to introduce a framework in which the behavior of socio-economical agents is modelled in terms of a game with continuous strategies. As a result, the emergence of stable network of relationships among agents can be seen from a dynamical system point of view in terms of stable equilibria in the evolution of agents' strategies. With symmetry arguments and some analytical work supported by computer simulations we try to relate the global properties of the system (emergence of stable structures) to the local interaction rule. The ultimate goal is to organize local interaction rule based on the stability properties that they produce. This work has lead to paper [10].

II. INFORMATION THEORY IN BIOLOGICAL NEURAL NETWORKS

Before turning to socio-economical networks I was involved in the study of biological neural network. The main question that my works try to address is how the a network of neural cells process the information about a stimulus. During my "Laurea" thesis work (one year) at **SISSA** (International School for Advanced Studies, Trieste, Italy, www.sissa.it) I did measurements of Mutual Information on multi-channel recordings from neural cell cultures and from the leech ganglion. It is quite clear that stimuli are encoded in a distributed fashion. Still the stochastic nature of the response makes it non trivial the characterization of such an encoding [2]. In the cortex, phenomena of non linear integration have been revealed [3]. One of the problems to tackle in extra-cellular recordings, is that the activity of several neurons is recorded at the same time from each channel. In order to investigate the information processing it is necessary to separate the signal of different neurons. Fortunately, in general each neuron produces a waveform (the shape of the action potential) specific to it and different from those of other neurons. I developed a user-interface software (with Matlab) to allow the user to classify semi-automatically the waveforms corresponding to different neurons. After having extracted the signal of few neurons from each recording channel (we had up to 100 channels) one can study the correlations between the activity of neurons that are at different locations in the network [1]. This work has been done first in the laboratory of Vincent Torre and then in the one of Mathew Diamond at SISSA.

III. UNPUBLISHED WORKS

A couple of research works were left in a "suspended" state on the way.

The first one is again in computational neuroscience, but it concerns a neural network model and not data analysis as before. The model reproduces some experimental evidence about the activity of neurons involved in **short-term memory** tasks. In the experiment we want to model these neurons are found to stay active during the whole time interval in which the subject has to keep in memory the stimulus. Moreover they encode the intensity of the stimulus in a linear fashion. The stimuli of this kind of experiments are "one-dimensional" as for instance the frequency of a vibration perceived on the skin or a visual angle (see www.lps.ens.fr/ battiston/ for more information). This work was the topic of a research assistant fellowship at the laboratory of XJ Wang, Brandeis Univ.

The other work is about **co-evolution of fractals**. Some iterated function systems (IFS) produce fractal invariant sets. The invariant set depends on the coefficient of the matrix defining the ISF. One can assign a fitness to the invariant set (the phenotype), based on some geometrical properties and evolve the coefficients of the ISF matrix (the genotype). I studied the co-evolution of two ISF's that are confined in a box and compete for space (see www.lps.ens.fr/ battiston/ for more information). This work started as a an assignment for the course in Machine Learning, in J. Pollack's lab DEMO, Brandeis Univ.