Minority Games and Distributed Coordination in Non-Stationary Environment

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Based on a paper with the same name authored by Aram Galstyan and Kristina Lerman, available at:

http://www.isi.edu/~lerman/papers/mg-conf.pdf

Introduction

- Minority Game (MG) – Introduced by Challet and Zhang in 1997, is a simple game with artificial agents with *partial information* and *bounded rationality*. It captures the essential feature of systems where agents compete for limited resources, like financial markets.
- Features of Standard MG:
  - There are N(odd) players
  - At each iteration they choose a side – A or B (0 or 1)
  - Players earn one point if they are in the minority
  - Each player knows what was the result of M previous time steps(the history)
  - Each player has S strategies
  - Model is completely defined given N,M,S

Branches of MG

- capacity level $\eta = 1/2$:
  - Standard MG : with *N* agents, each has *M* memory sizes and *S* strategies. *2* choices
  - Evolutionary MG: has only 1 strategy *S*, each agent *i* has a probability p_i to choose using the strategy *S* or not. *Evolutionary* means that if an agent has a wealth smaller that d, his p_i is changed within a range of R. 2 choices
  - Multi-choices MG: number of choices > 2. Other features = Standard MG
  - Hierarchical MG: MG using local histories, and integrated by higher level MG.
- Capacity level $0 < \eta < 1$
  - Generalized MG

In the above 2 categories, environments are stable.

- Propose of non-stationary environments:
  - By Aram Galstyan and Kristina Lerman at 2002
  - MG with arbitrary capacities: $\eta(t) = \eta_0 + \eta_1(t)$

The winning choice is "1" if $A(t) \leq L$ where *L* is the capacity, *A(t)* is the number of agents that chose "1"

Model of Non-stationary Environments (Kauffman Networks)

- A set of N boolean agents, choose between 0 and 1: $s_i=\{0,1\}$, $i=1,\ldots,N$.

$$s_i(t+1) = F_i^j(s_{k1}(t), s_{k2}(t), \ldots, s_{kK}(t))$$

where s_{ki}, $i=1,\ldots,K$ *are the set of neighbors*

- Strategy: F_i^j, $j=1,\ldots S$, are called a strategies, which are a set of S randomly chosen boolean functions used by agent *i*, and the score of F_i^j at time step t is $U_i^j(t)$.
- Capacity Level: $\eta(t) = \eta_0 + \eta_1(t)$
- Attendence: $A(t) = \sum_{i=1}^{N} s_i(t)$

so, if $A(t) <= N\eta(t)$, the winning choice is "1", and "0" otherwise.

Model of Non-stationary Environments (cont.)

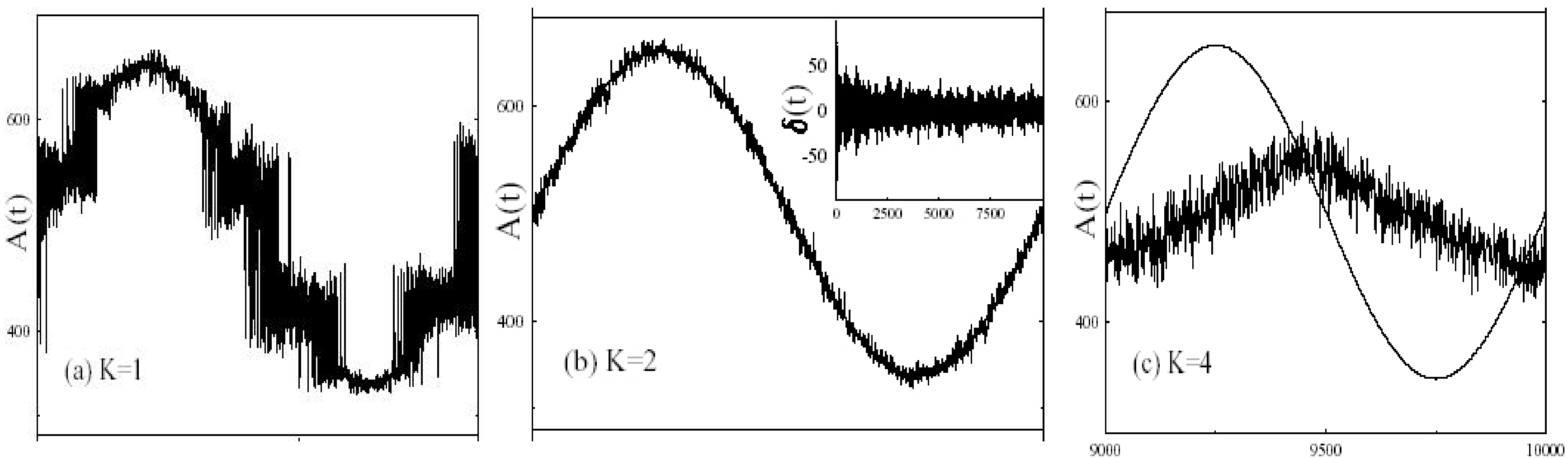
- $\delta(t) = A(t) - N\eta(t)$, which describes the standard deviation from the optimal resource utilization.
- The Global measure for optimality σ^2 is defined as:

$$\sigma^2 = \frac{1}{T_0} \sum_{t=t_0}^{t_0+T_0} \delta(t)^2$$

when $\eta_1(t)=0$, this quantity is the squared standard deviation in traditional MG.

- In the following experiments, the parameters are:
  - N: 100~5000
  - S = 2 , which is chosen randomly from 2^{2^k} possible boolean functions.
  - Using different forms of $\eta(t)$.

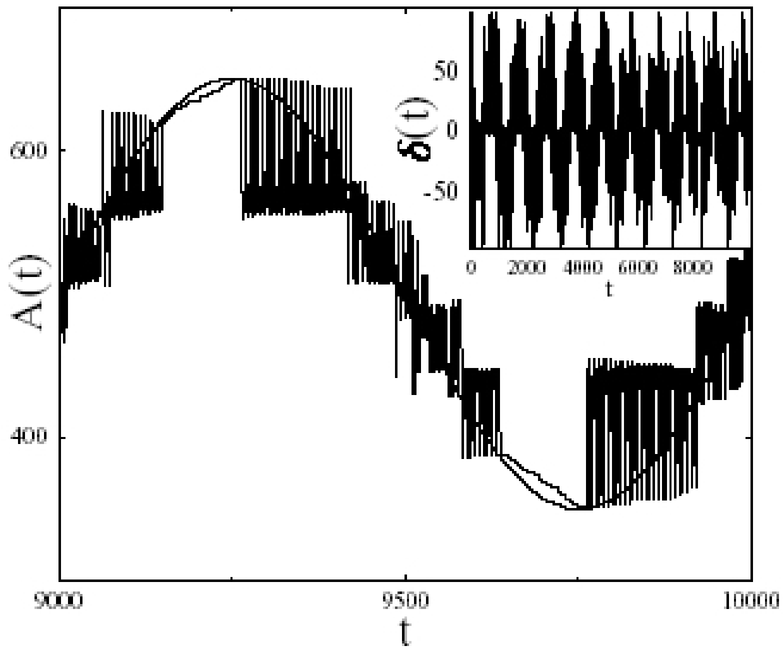
Experimental Results -- I



A segment of the attendance time series for $\eta(t) = 0.5 + 0.15\sin(2\pi t/T)$, $T=1000$ and different network connectivity K.

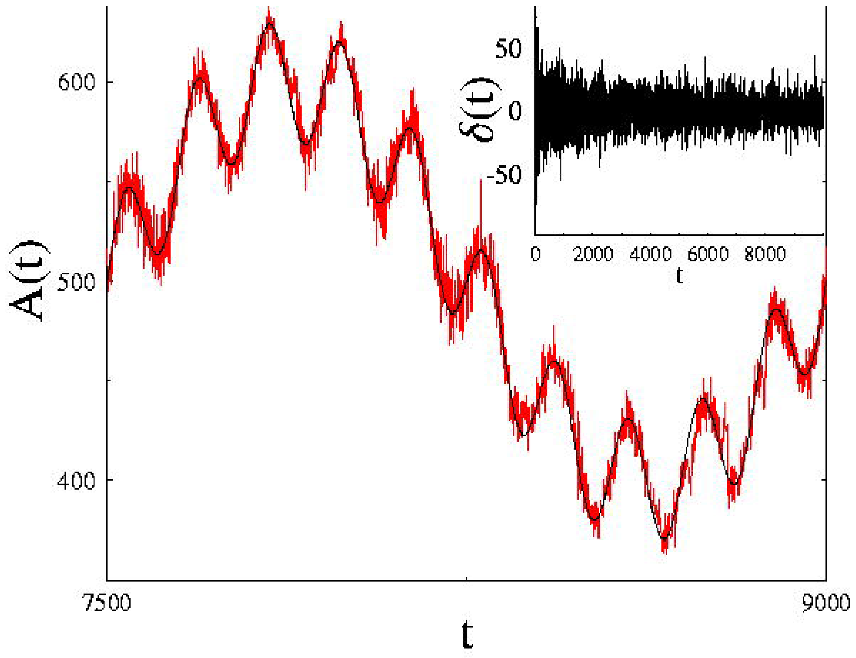
- K<2: the network reaches a frozen configuration
- K=2: networks show a tendency towards self-organization into a coordinated phase characterized by small fluctuations and effective resource utilization
- K>2: the dynamics of the system is chaotic.

Experimental Results -- II



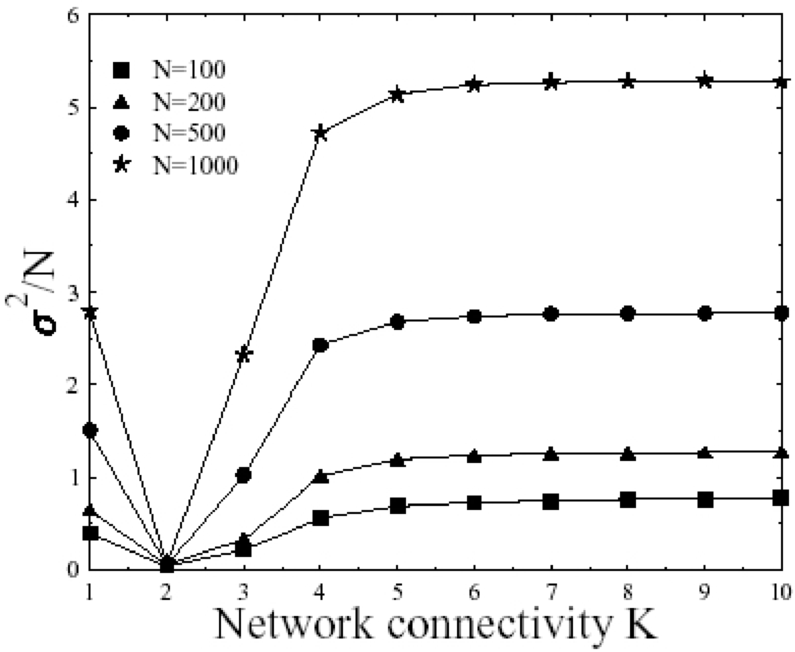
- Use the model of traditional MG with M=6, which corresponding to the minimum of σ.
- Use the same *η(t)* as in the last experiment.
- Results:
  - The system reacts to the external change.
  - The overall performance in terms of resource allocation as described by σ is much poorer.
  - The distribution of wealth among the player is much wider than in the system with local information exchange---more fair.

Experimental Results --III



Coordination occurs even in the presence of vastly different time scales in the environmental dynamics

Experimental Results -- IV



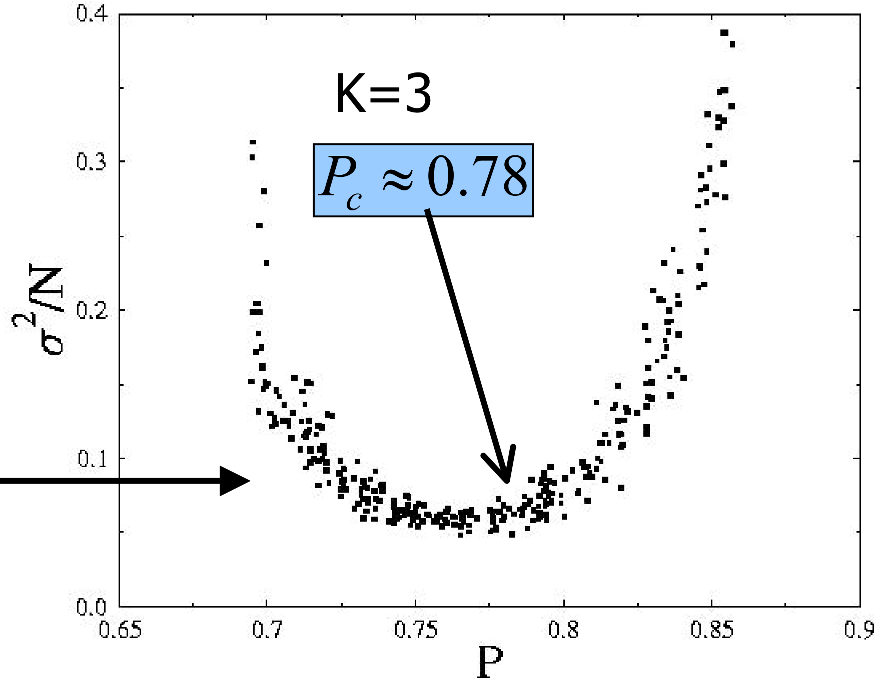
- The variance reaches minimum value when K=2, and is independent of the number of agents in the system $\sigma^2/N \approx const$ ---- different with traditional MG.
- When K increases, the variance is tend to flat and depends on the amplitude of the perturbation and the number of agents in the system.
- When K=2, $\sigma \propto N$; for others, $\sigma \propto N^{1/2}$.

Phase Transitions in Kauffman Nets

Kauffman Nets: phase transition at K=2 separating ordered (K<2) and chaotic (K>2) phases

For K>2 one can arrive at the phase transition by tuning the homogeneity parameter P (the fraction of 0's or 1's in the output of the Boolean functions)

The coordinated phase might be related to the phase transition in Kauffman Nets.



Summary of Results

- Generalized Minority Games on K=2 Kauffman Nets are highly adaptive and can serve as a mechanism for distributed resource allocation
- In the coordinated phase the system is highly scalable
- The adaptation occurs even in the presence of different time scales, and without the agents explicitly coordinating or knowing the resource capacity
- For K>2 similar coordination emerges near the phase transitions point of the ordered/chaotic phase in the corresponding Kauffman Networks

Problems

- Lack of sufficient experiments on other important factors of MG, for example, the number of strategies $S = 2$, how about other number of S?
- The author compares the performance of Kauffman MG model with $K=2$ with standard MG model with $M=6$. Actually K can be mapped to M, so why not compare with $M=2$?

  (The assumption of MG is, the agents only know about the global signal, however in this Kauffman MG model, the strategy is based on other input of its neighbors. I think this is a very large difference, so the comparison with standard MG is improper)
- Only the periodic perturbations are used to change the capacity level: $\eta(t) = 0.5+0.15\sin(2\pi t/T)$. How about the random disturbance or other forms of distributions to the capacity level? For example, Gaussian Distribution.
- In our search, can we can use the evaluation function to adjust the capacity level? This attempt should be carried out in 2 steps:
  - Learn the function between the evaluation of RSL and the specific problem we want to address, e.g., the real-time roles distribution in terms of the evaluation of RSL.
  - Use the real-time roles distribution as the capacity function in Kauffman MG model

Appendix: Kauffman Network

Consider a network of N agents where each agent is assigned a Boolean variable $\sigma_i = 0$or 1. Each agent receives input from K other distinct agents chosen at random in the system. The set of inputs for each agent i is quenched. The evolution of the system is specified by N Boolean functions of K variables, each of the form

$$\sigma_i(t+1) = f_i[\sigma_{i_1}(t), \sigma_{i_2}(t), \ldots \sigma_{i_K}(t)]. \qquad (1)$$

There exist 2^{2^K} possible Boolean functions of K variables. Each function is a lookup table which specifies the binary output for a given set of binary inputs. In the simplest case defined by Kauffman, *where the networks do not organize*, each function f_i is chosen randomly among these 2^{2^K} possible functions with no bias; we refer to this case as the random Kauffman network (RKN).

Reference: Maya Paczuski, Kevin E. Bassler, Alvaro Corral, Self-organized networks with competing boolean agents, Phys. Rev. Lett. 84, 3185-3188 (2000).