Istituto Nazionale di Fisica Nucleare

SM&FT 2017 - The XVII Workshop on Statistical Mechanics and nonpertubative Field Theory

Collective Intelligence of Human Groups in presence of 'Contrarians'

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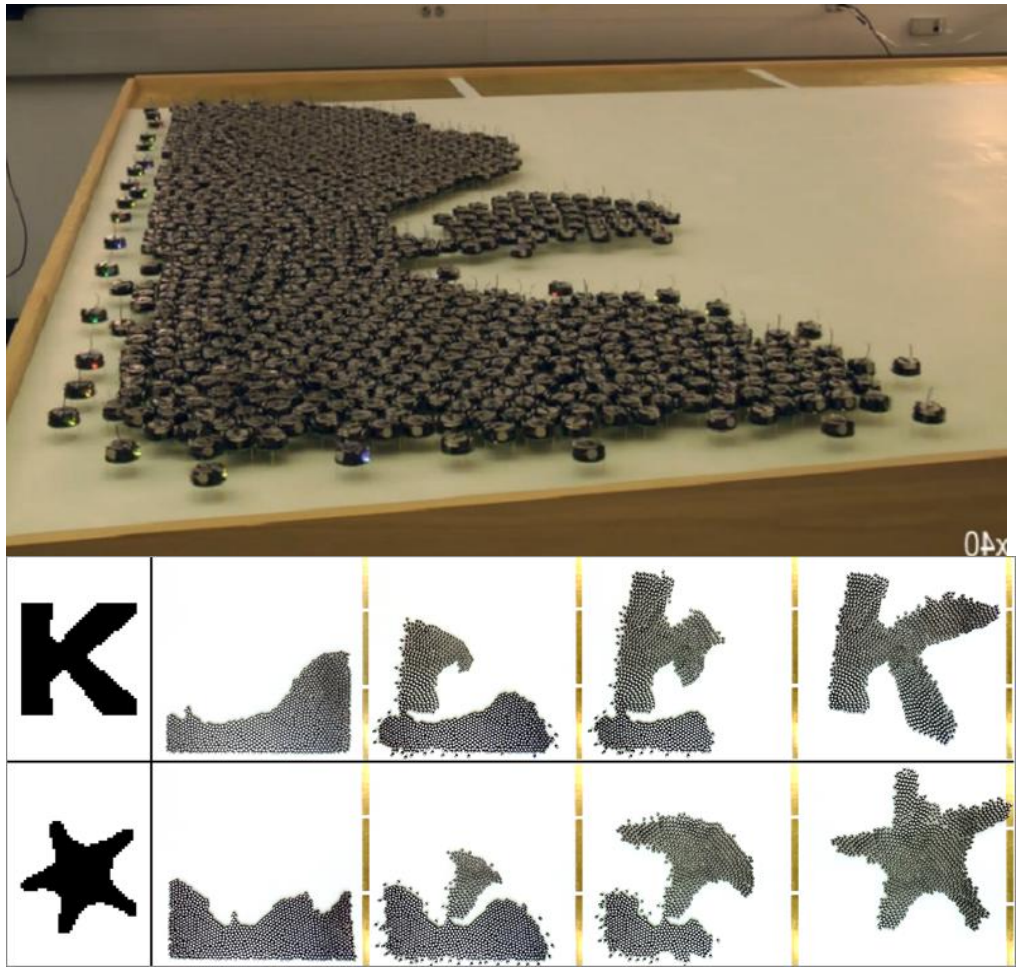
Collective Intelligence

- Each single agent makes simple actions
- Each agent interacts with its neighbors
- No centralized control
- The resulting complex dynamics of the swarm is governed by a few control parameters
- A superior intelligence (swarm intelligence) of the group emerges at critical values of the control parameters
- Swarm intelligence provides the swarm with high ability and flexibility in solving many different complex tasks



https://youtu.be/xK54Bu9HFRw?t=71

Rubenstein M., Cornejo A., Nagpal R.,
Programmable Self-Assembly in a Thousand-Robot Swarm**,** *Science*, **345** (6198) 2014.

Motivation

- The ability of groups in solving decision making problems (collective decision making) is recognized in a variety of contexts
  - Animals, artificial systems, humans
- It originates from the social interactions taking place among individuals in groups. Their main tendency is to avoid conflict with people they interact with.
- However, in recent years, examples of social systems exhibiting individuals who prefer to disagree with everybody else, have become the rule rather than the exception.
- Decision making performance and dynamics are influenced by ‘contrarian’ agents, who slow down consensus seeking process.

Aim of the research

- To investigate on the effect of ‘contrarian’ agents on:
    - Decision making performance of human groups.
    - Critical conditions, which lead to the emergence of collective intelligence in human groups.

Decision Making Model – State of Art

- **Humans solve complex problems by using a search process**
  - Make a choice and modify it, so as to explore the decision space and attempt to identify the best solution (Levinthal 1997; Katila and Ahuia, 2002; Mihm, Loch and Huchzermeier, 2003)
- **Decision making of human groups is described by DMM (G. Carbone, I. Giannoccaro, 2005)**
  - Humans are self-interested and cognitively constrained. (Simon, 1957, 1979)
  - Humans have a natural tendency to seek consensus and avoid conflict with people they interact with. (DiMaggio and Powell, 1983)
  - Self-interest and consensus seeking drive human rational decision making.
- **The problem consists in finding the optimum on a complex fitness landscape**
  - Once the complex landscape is chosen, the aim is to find the most effective combination

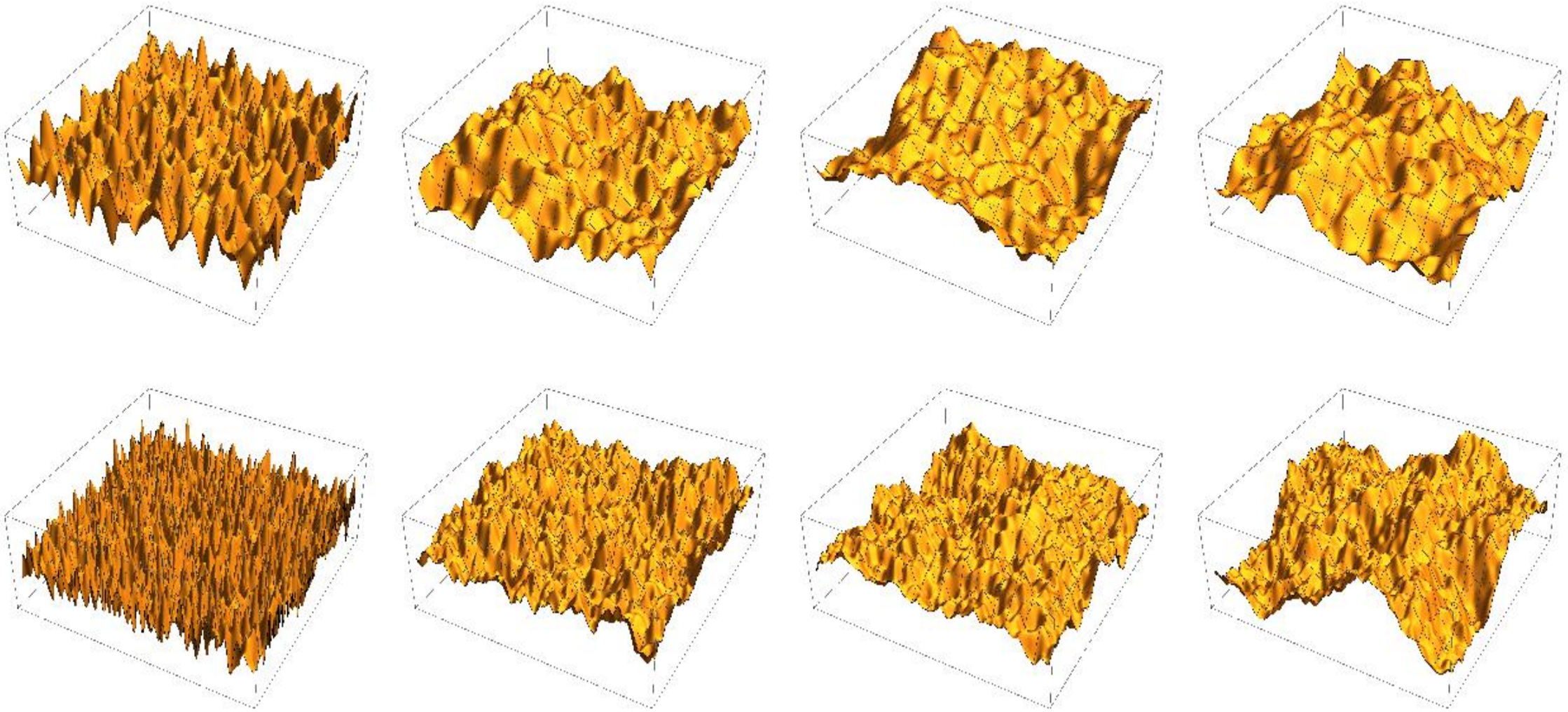
    of the decisions variables.
  - The DMM models the search process on the *NK* Kauffman fitness landscape (Kauffman 1987).

    However….

Examples of complex landscapes

White noise

Fractal Dimension



Complexity

NK Fitness Landscape

- Parameters of the *NK* Kauffman fitness landscape

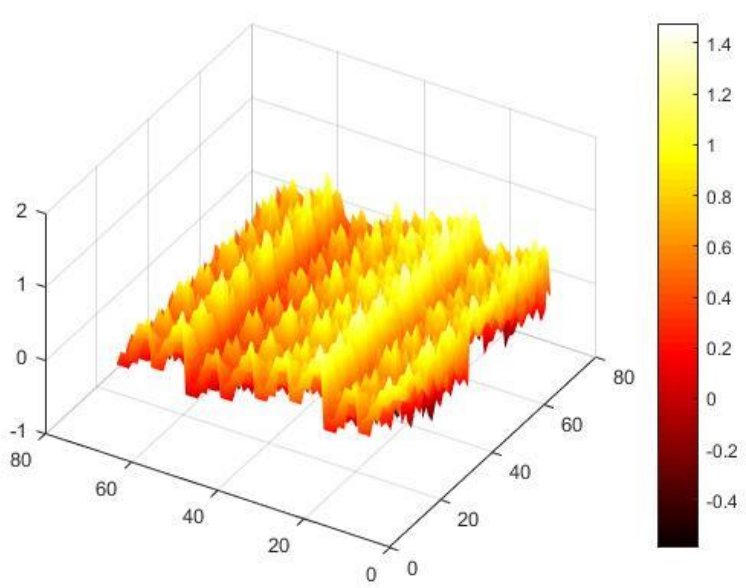
  N – Number of binary decisions

  $\boldsymbol{d} = (d_1, d_2, \ldots d_N)$, the vector of decision values

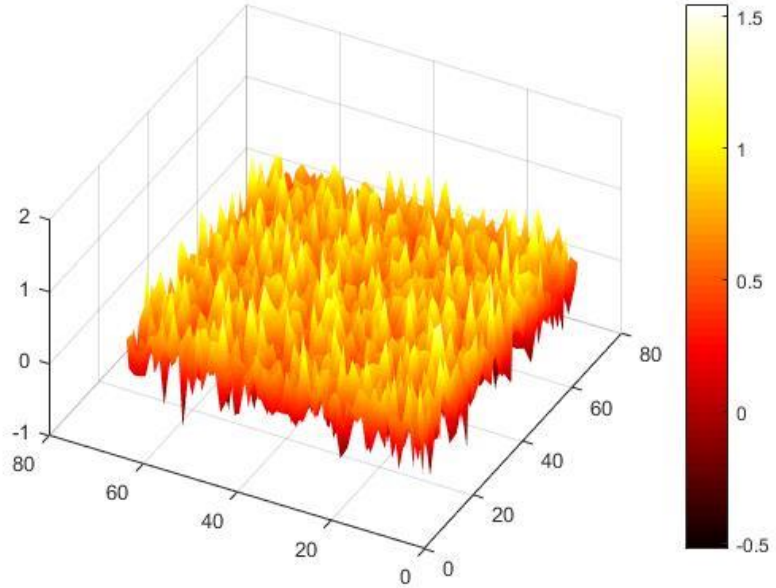
  K – Number of interacting decisions

  The pay-off function $V(\mathbf{d})$ associates a fitness value to each vector **d**

N and K control the complexity of the problem $\Rightarrow \boldsymbol{C = K + 1 + log_2 N}$



COMPLEXITY



The model: pay – off function

- The contribution W_j of the *j*-th decision to the overall performance depends not only on the value d_j of the decision *j* but also on *K* other decisions (d_{j1}, d_{j2},…, $d_{j,K}$).
- The overall pay-off is the average of all the contributions W_j:

$$V(\mathbf{d}) = \frac{1}{N}\sum_{j=1}^{N} W_j\left(d_j, d_1^j, d_2^j, .., d_K^j\right)$$

- The information associated with the landscape is completely stored in a matrix of size $2^{K+1} \times N$

The model

- The state vector of the whole system, has $n = N \times M$ component, leading to

$$\boldsymbol{s} = (s_1 s_2, .., s_N) = (\sigma_1^1, \sigma_2^1, .., \sigma_M^1, \ldots, \sigma_1^N, \sigma_2^N, .., \sigma_M^N)$$

- The dynamics of the M members making N decisions is formulated in terms of the dynamics of a larger team of $n = M \times N$ members.
- A continuous – time Markov chain governs the dynamics of the system. Let P(**s**,t) be the probability that at time t the state vector takes the value **s** out of 2^n possible states.

MASTER EQUATION

$$\frac{dP(\sigma)}{dt} = -\sum_k w(\sigma_k) P(\sigma_k) + \sum_k w(-\sigma_k) P(-\sigma_k)$$

G. Carbone, I. Giannoccaro, The European Physical Journal B, **88** (12), 339 (2015)
I. De Vincenzo, I. Giannoccaro, G. Carbone, P. Grigolini, Physical Review E, **96**, 022309, (2016)

Transition Rate

- Let the member *i* have an opinion σ_k
- The transition rate $w(\sigma_k)$ is defined as the product of social interaction rate (Ising/Glauber) and the exponential rate (Weidlich) related to perceived pay-off:

$$w(\sigma_k) = \underbrace{\frac{1}{2}\left[1 - \sigma_k \tanh\left(\beta J A_{kh}\sigma_h\right)\right]}_{\textbf{Ising/Glauber}} \underbrace{\exp\left(\beta' \Delta V_P^{(i)}\right)}_{\textbf{Weidlich}}$$

- $\mathbf{A} \equiv A_{kh}$ is the adjacency matrix of the team social network
- β is the inverse of social temperature
- J is the strength of the mutual social interaction between neighbors
- β' is related to the degree of uncertainty associated with the knowledge of the fitness landscape (the higher β', the less the uncertainty)
- $\Delta V_P^{(i)}$ is the change in pay-off perceived by member *i* when the opinion flips from σ_k to $-\sigma_k$

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Performance measurements

- Efficacy of group in making decisions
  - Average of V[**d**(t)] over multiple simulation runs (<*V*>)
    - Where V[**d**(t)] is the payoff of the group decisions **d**=(d_1,d_2,…d_N) made at time t
    - The majority rule is applied to define each d_j at any time *t*
- Level of consensus

$$\langle C(t)\rangle = \frac{1}{M^2 N}\sum_{j=1}^{N}\sum_{kh=1}^{M}\langle \sigma_k^j(t)\,\sigma_h^j(t)\rangle$$

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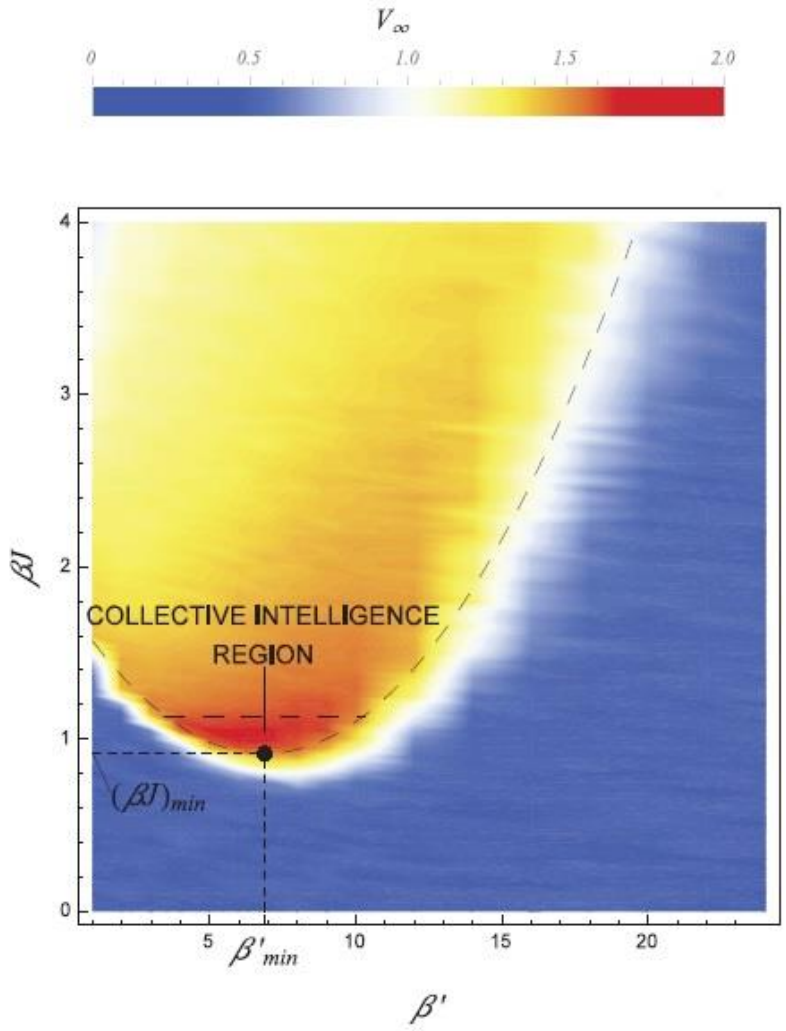
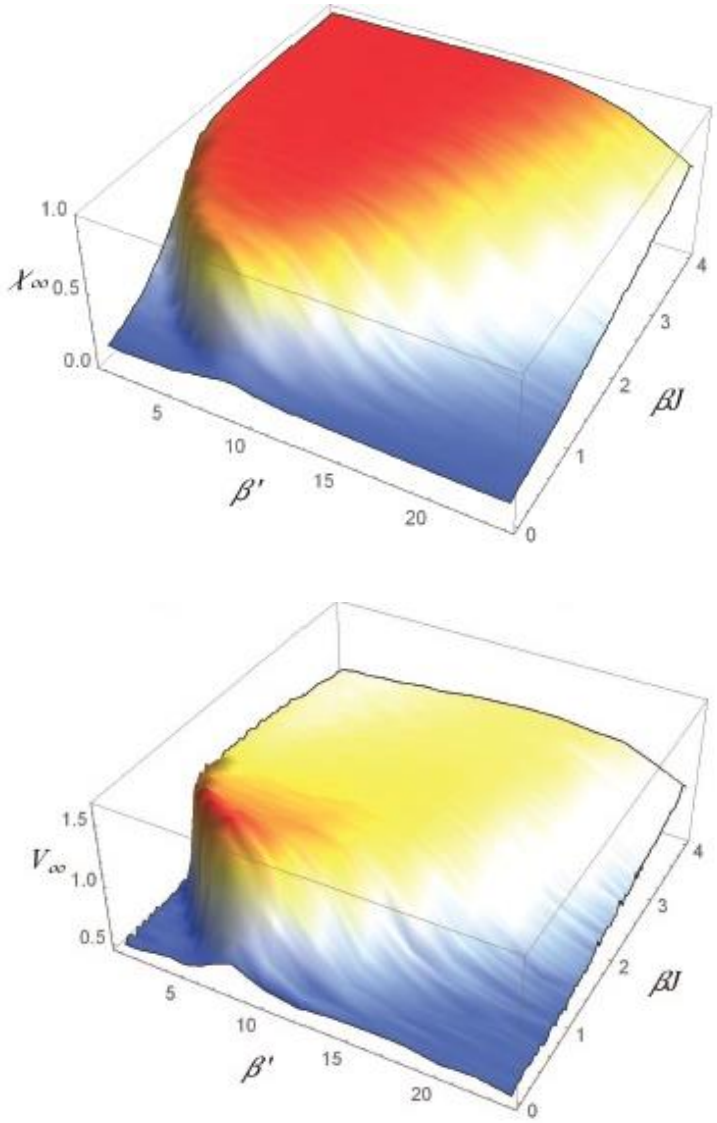
Critical Conditions





PARAMETERS

$M = 7$
$N = 15, K = 14$

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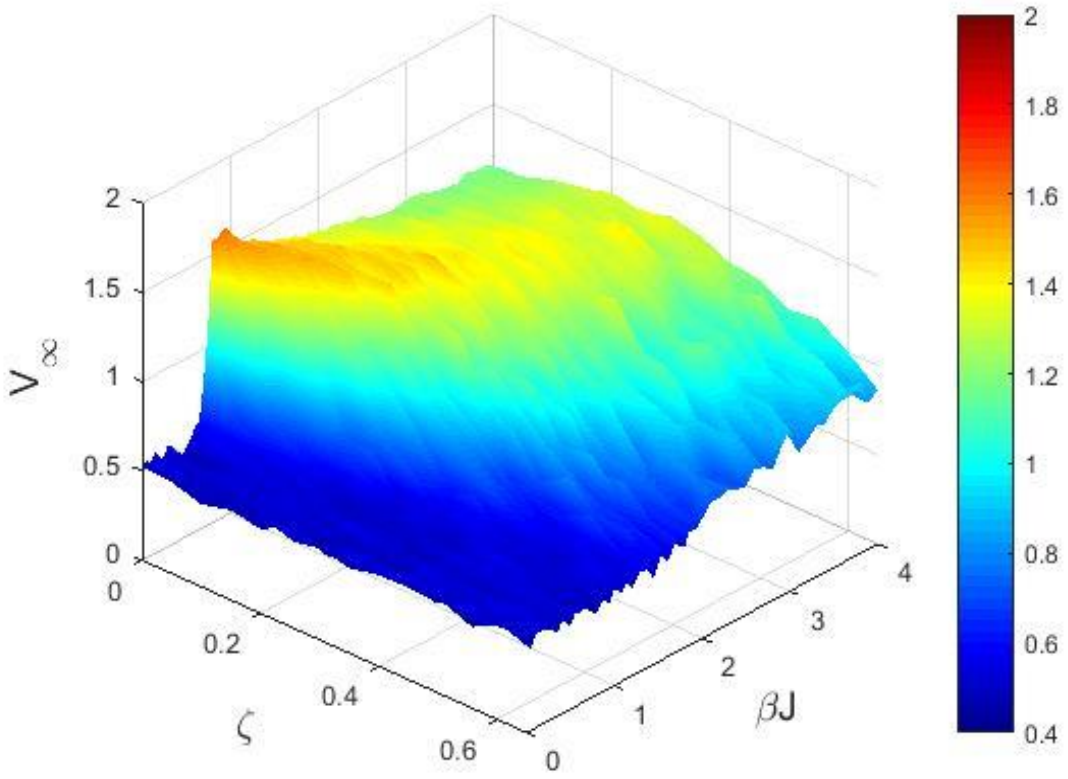
How ‘contrarians’ affect team performance?



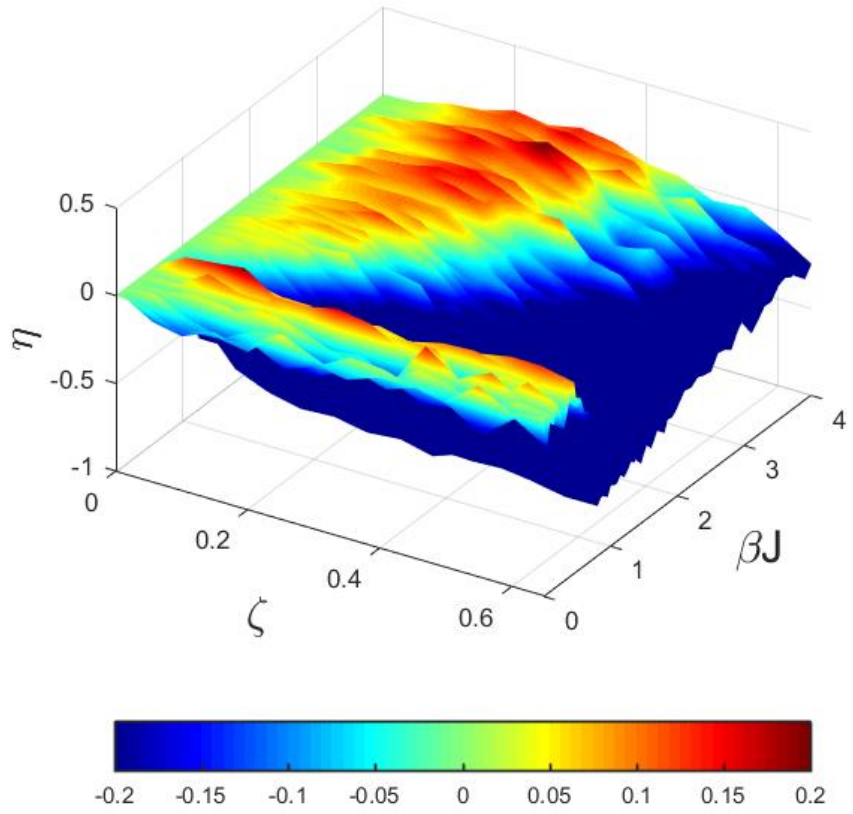
- We select at random with probability ζ a social link and assigne it a negative value of social interaction strength (*‘anti-consensus’* interaction).
- Team performance are presented in terms of 3D map, as function of $(\zeta, \beta J)$.
- We find that at low values of social interaction strength βJ the presence of “anti-consensus” interactions is always detrimental in terms of decision making performance of the team.
- However, at relatively high βJ values, a moderate value of $\zeta = 0.25$, enhances the performance of the group.

PARAMETERS

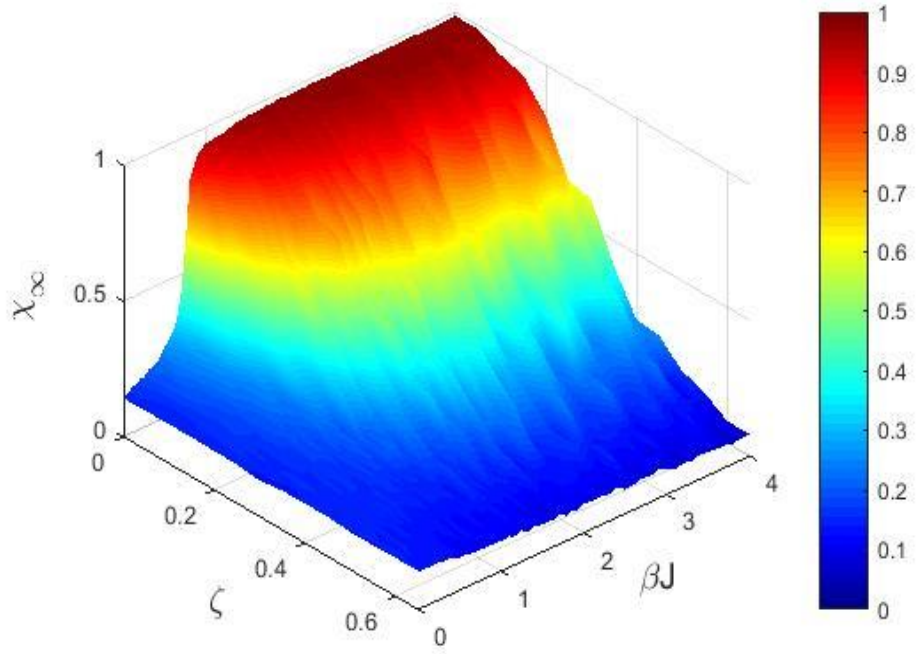
$M = 7, \beta' = 7$
$N = 15, K = 14$

G.F. Massari, I. Giannoccaro, G. Carbone, ‘The effect of contrarians on the decision making performance of groups’, COMPLENET 2018, Boston, March 2018.

The efficiency



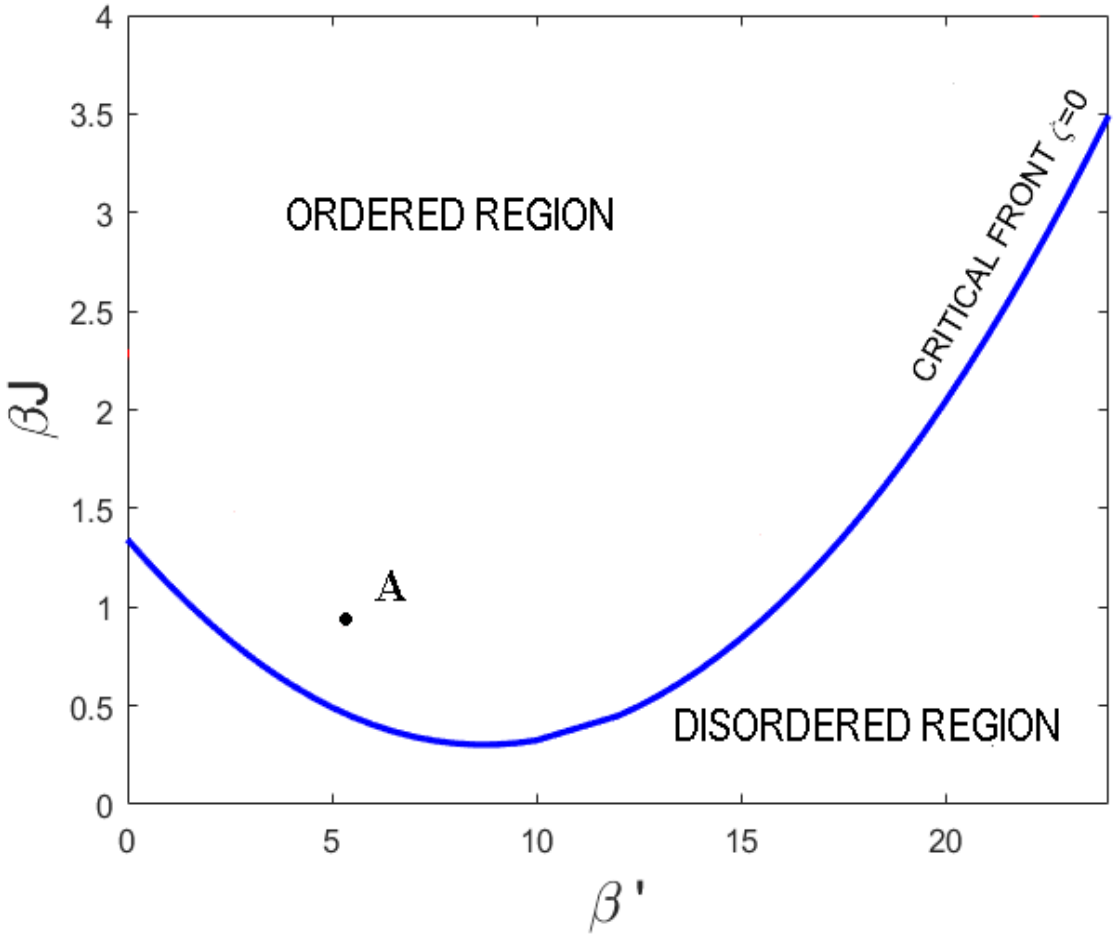
$$\eta = \frac{V_\infty(\zeta) - V_\infty(\zeta = 0)}{V_\infty(\zeta = 0)}$$



- In the region of high βJ values (red color), the presence of a moderate number of '*anti-consensus*' interactions, slows down the process of consensus seeking thus improving the exploration of the landscape and enabling the group to find better solutions.

G.F. Massari, I. Giannoccaro, G. Carbone, 'The effect of contrarians on the decision making performance of groups', COMPLENET 2018, Boston, March 2018.

Critical conditions



- Critical front in absence of *'anti-consensus'* interactions, $\zeta = 0$.
- Let suppose that, the state of the system is represented by point $A(\beta_A', \beta J_A)$, in the ordered region, far from the critical front.

TEAM PERFORMANCE

- Fast consensus seeking ⇒ Low group payoff.

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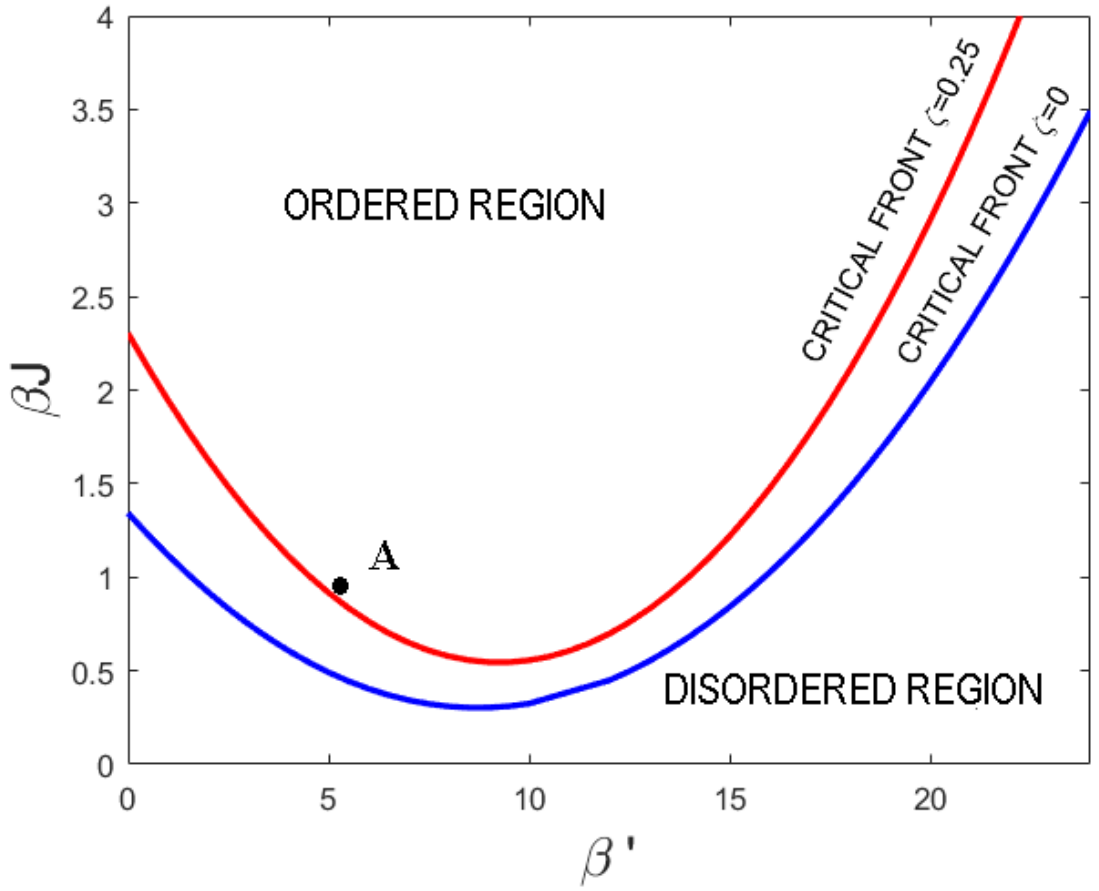
Critical conditions



- The effect of contrarians almost rigidly displaces the U-shaped front towards higher values of βJ.
- Now, the state of the system, still represented by point $A(\beta_A', \beta J_A)$, is located in the ordered region but close to critical conditions.

TEAM PERFORMANCE

Criticality conditions ⇒ High group payoff.

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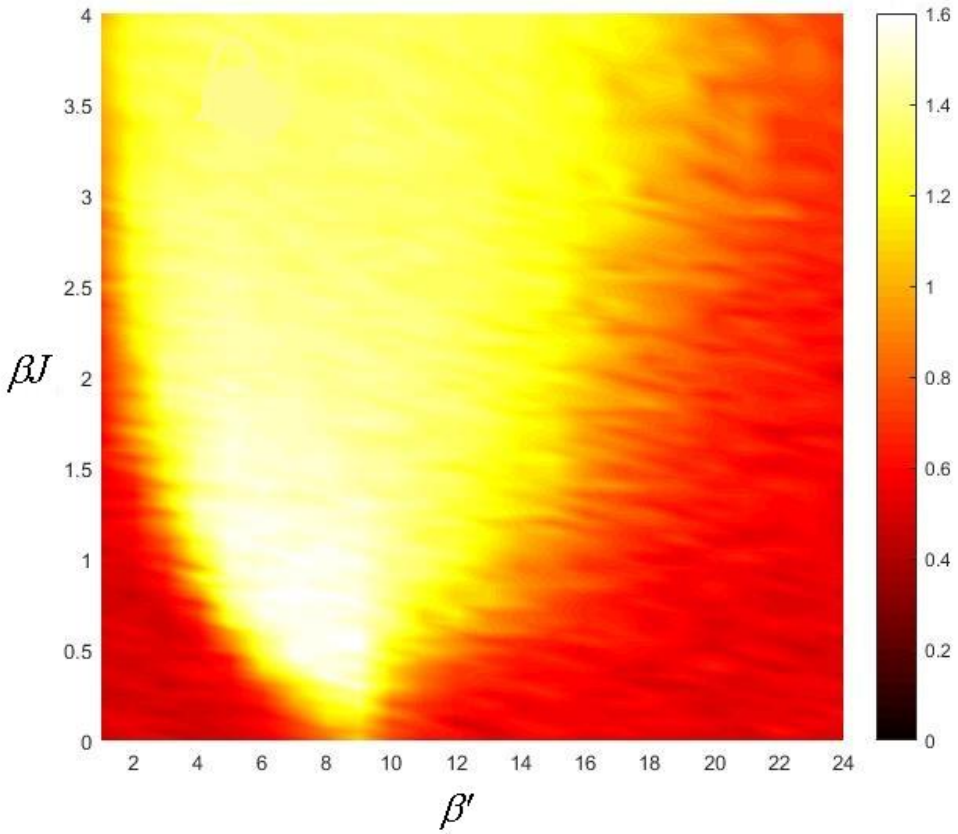
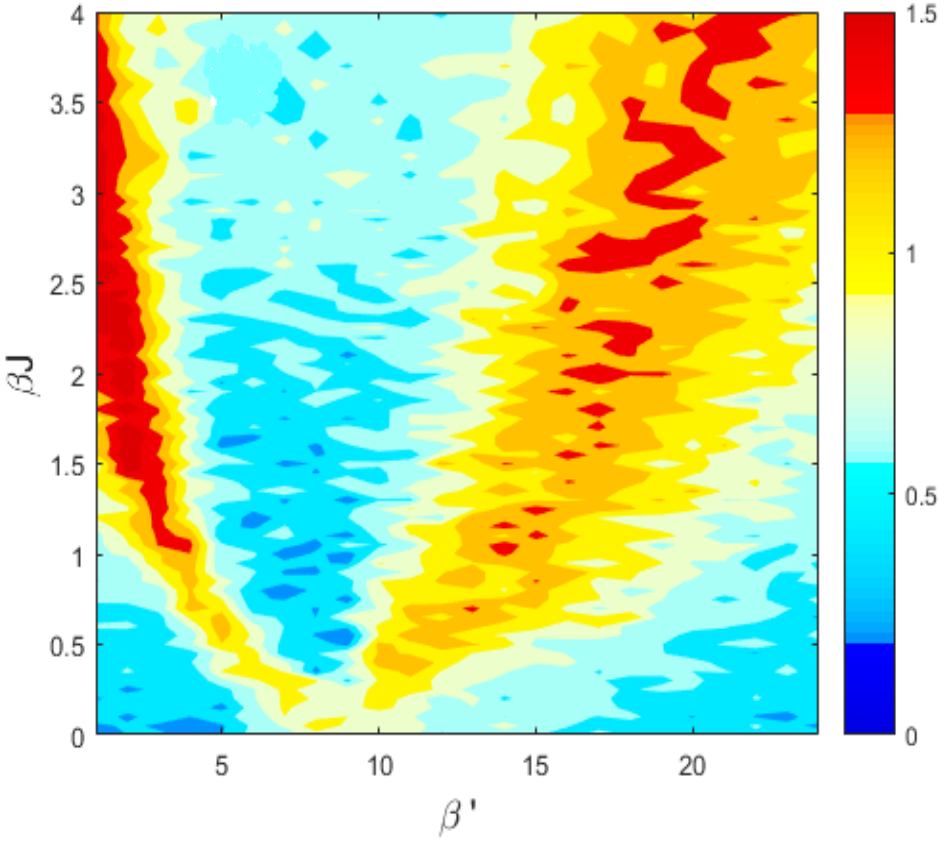
The Emergence of Collective Intelligence

V_∞



$MI(\chi_\infty, V_\infty)$



$$MI(X,Y) = \sum_{kh} p(x_k, y_h) \left[\log_2 \frac{p(x_k, y_h)}{p(x_k)\, p(y_h)} \right]$$

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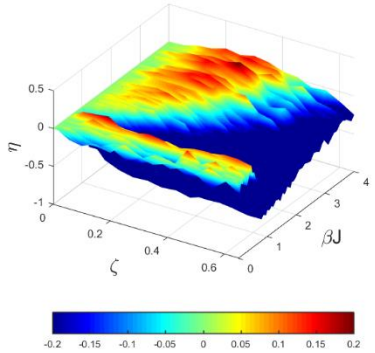
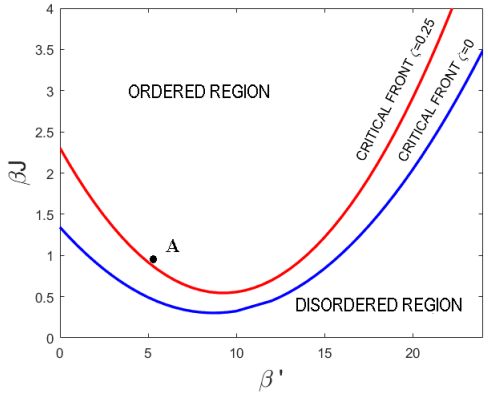
Conclusions

….. Effect on Team Performance.



- The presence of a moderate number of contrarians slows down the process of consensus seeking, thus improving the exploration of the landscape and enabling the group to find better solutions.

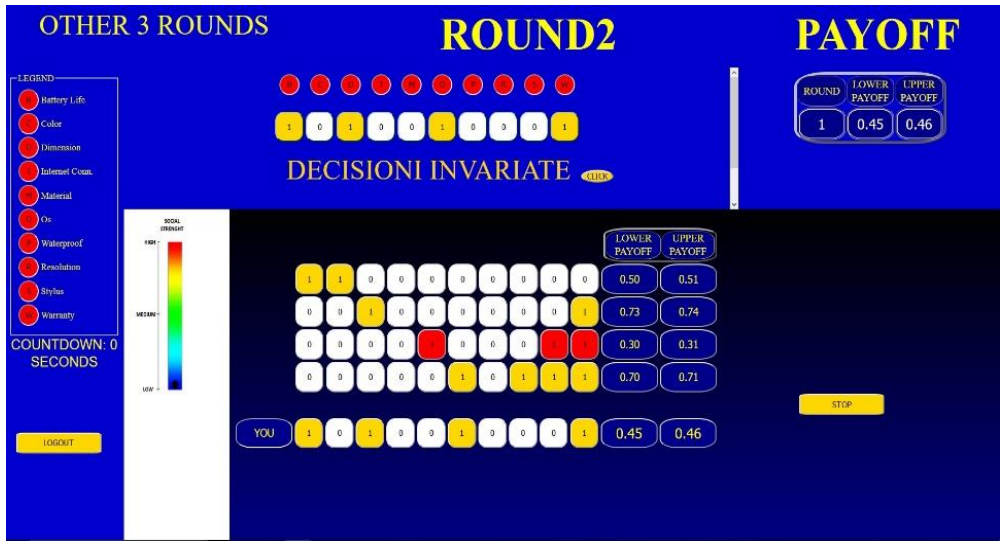
….. Effect on dynamics.

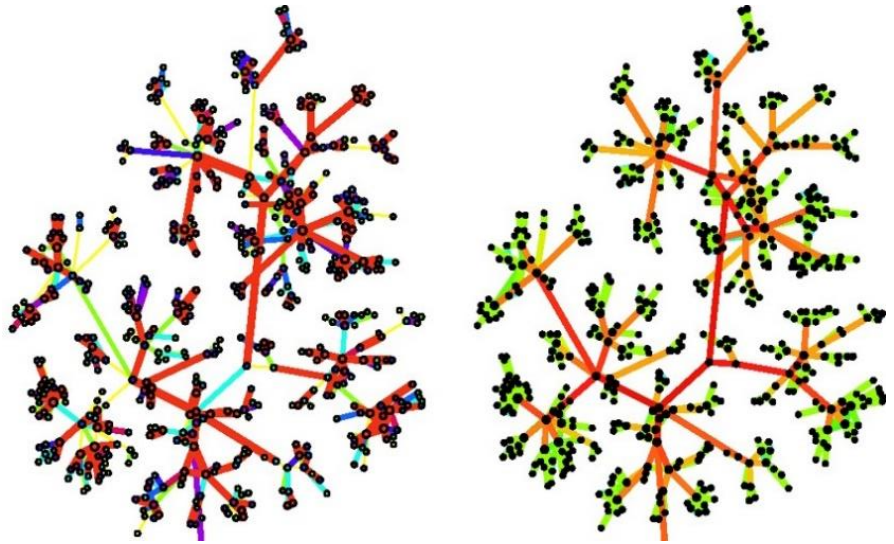


- A group characterized by a high value of social interactions strength, which would be characterized by low performance, can reach criticality and become intelligent by introducing a certain percentage of contrarians.

Further developments

- Experimental investigation to ascertain the existence of critical phase transition leading to the emergence of collective intelligence in human groups.
- Assessment of the effect of network structure on the decision making process.





THANKS FOR

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