Spatial Prisoner´s Dilemma in an Adaptive Network

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- M. Zimmermann et al, Phys. Rev. E. 69, 065102-6 (2004)
- V. M. Eguíluz, M. Zimmerman, C. Cela-Conde and M. San Miguel Cooperation and emergence of role differentiation in the dynamics of Social Networks, American Journal of Sociology 110, 977 (2005)

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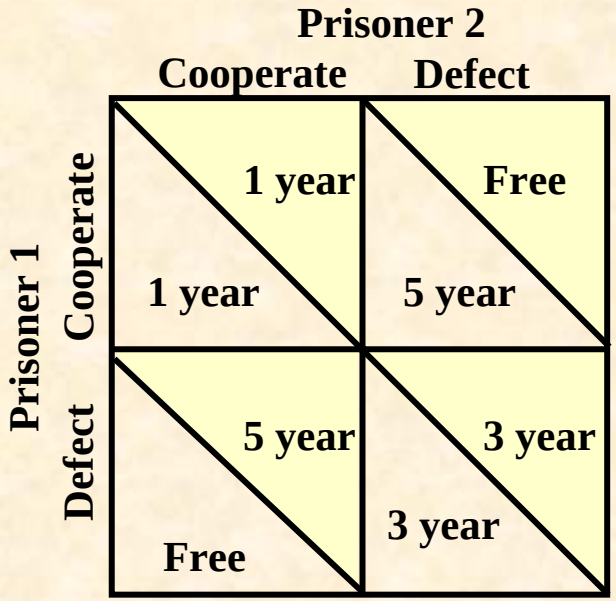
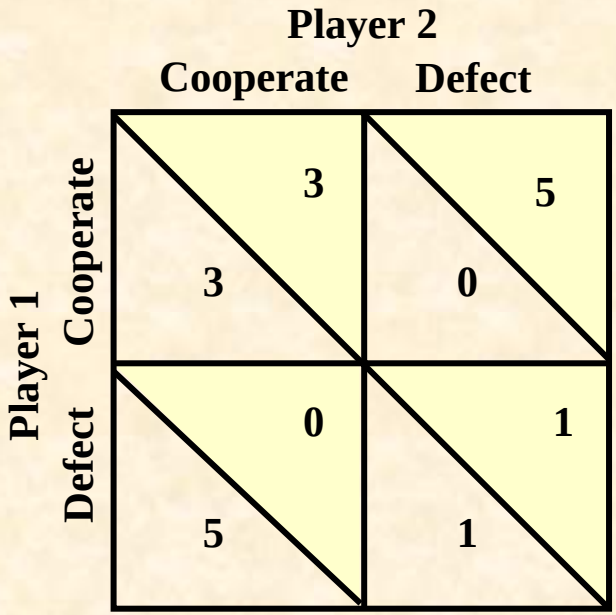
Paradigm for studies of cooperative behavior

Prisoner's Dilemma





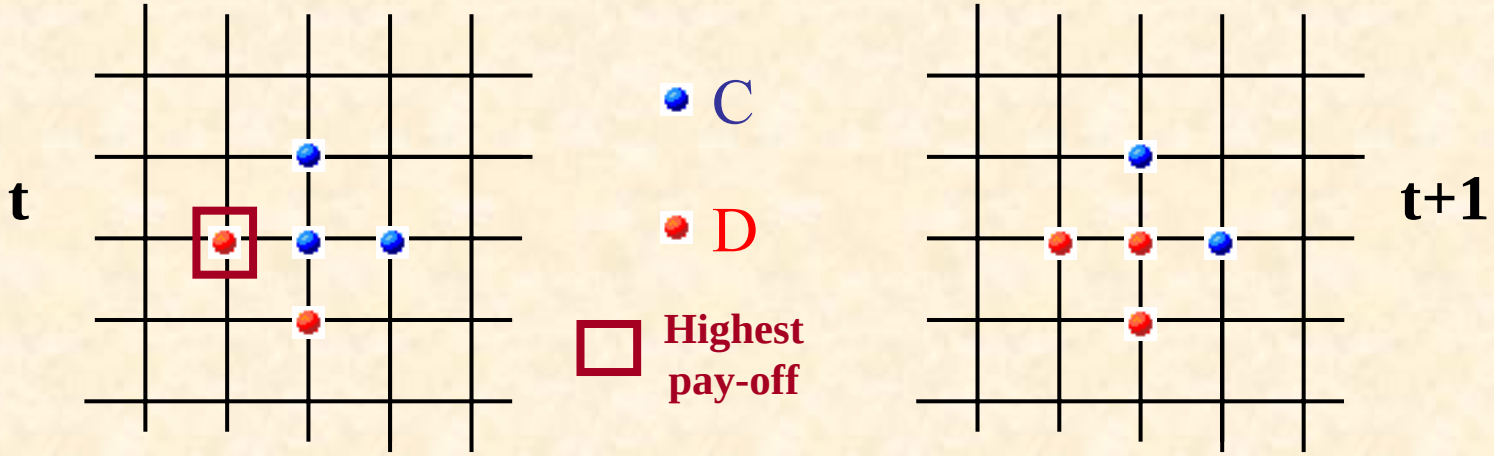
General problem:

- Whenever there is a conflict between self-interest and the common good.
- You are tempted to do something, but know it would be a great mistake if everybody did the same thing.

***'The origins of virtue'*, Matt Ridley (1996)**

Alternative route to cooperation: Spatial games

Spatial effects can mantain coexistence between cooperators and defectors in a single non-repeated PD. A spatial game leads to results essentially different of those obtained in a global game. **(M. A. Nowak and R. M. May, Nature 359, 826 (1992); Proc. Nat. Acad. Sci. USA 91, 4877 (1994)**



•*Players are only pure cooperators* **C** *or pure defectors* **D**. *No memory or strategy.*

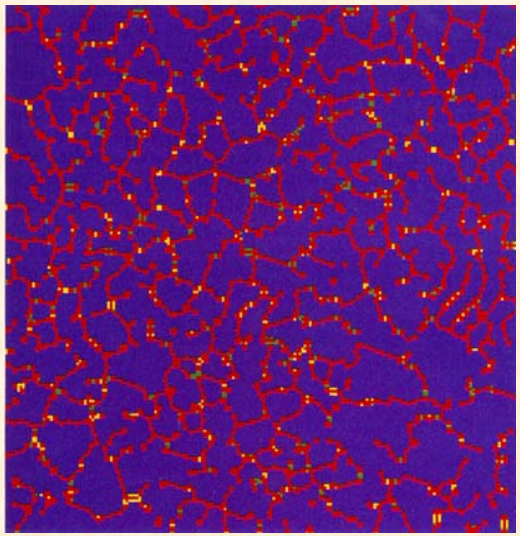
• *They interact with neighbors in some spatial array.*

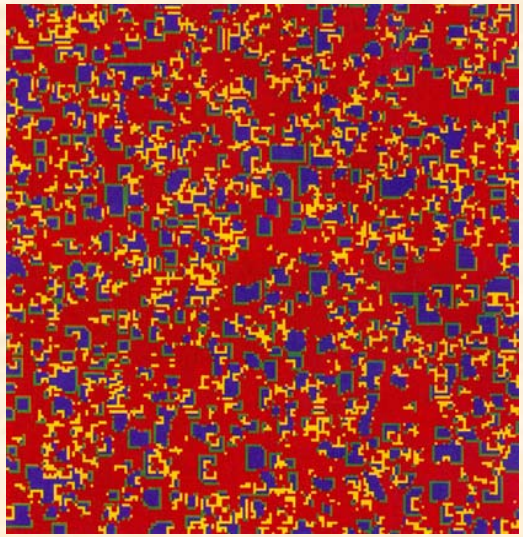
•*In each generation, players add up the scores from all encounters, and in the next generation a given cell is retained by its previous owner or taken over by a neighbor, depending on who has the largest pay-off.*

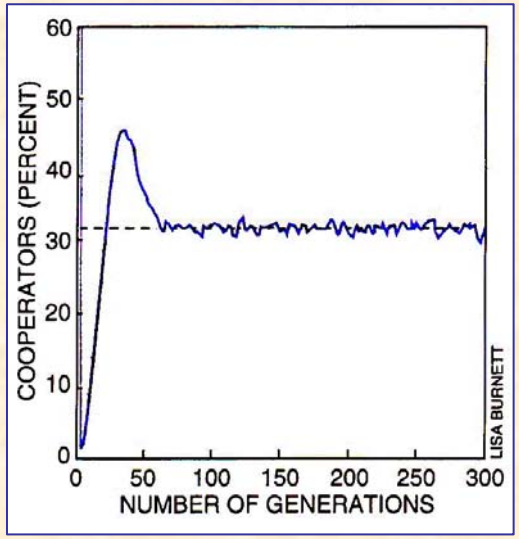
Spatial Prisoners´ Dilemma

A simple spatial version of the PD, with no memories among players and no strategical ellaboration can promote the coexistence of C and D in situations where one strategy would exclude all others if the interactions occurred randomly and homogeneously.

(M. A. Nowak and R. M. May, Nature 359, 826 (1992))







1.75<b<1.8

B=C (from C); R = D (from D)
Y=D (fromC); G = C (from D)

1.8<b<2

Regular network,
Deterministic winning,
Discrete time:Synchronous update

Locality/clustering or Context Preservation (continuity of interactions) **?**

(M. Cohen, R. Riolo and R. Axelrod, Rationality and Society 13, 5 (2001))

Co-evolution: PD game in a dynamic network

- **Motivation**: Adaptation of local neighborhoods: "*I no longer want to play with you!!*"

  Example: scientific collaboration networks

- **Probabilistic**: Social plasticity ***p***

  (a) dependent *(coupled evolution)*

  (b) non-dependent on strategies.

- **'Rational'**: *A new link is created whenever both agents receive a benefit. If both do not benefit, the link is dismissed.*

Network adaptation is based on mutual benefit

- **C-C link**: Mutual benefit = 2R (2)

  Both agents reinforce their relationship;

- **C-D link:** Mutual benefit = T+S (b)

  C-agent will try to dismiss, while D-agent will try to reinforce;

- **D-D link:** Mutual benefit = 2P (0)

  Both agents try to dismiss the relationship. (WEAKEST link)

Network adapts breaking the link D-D with probability p

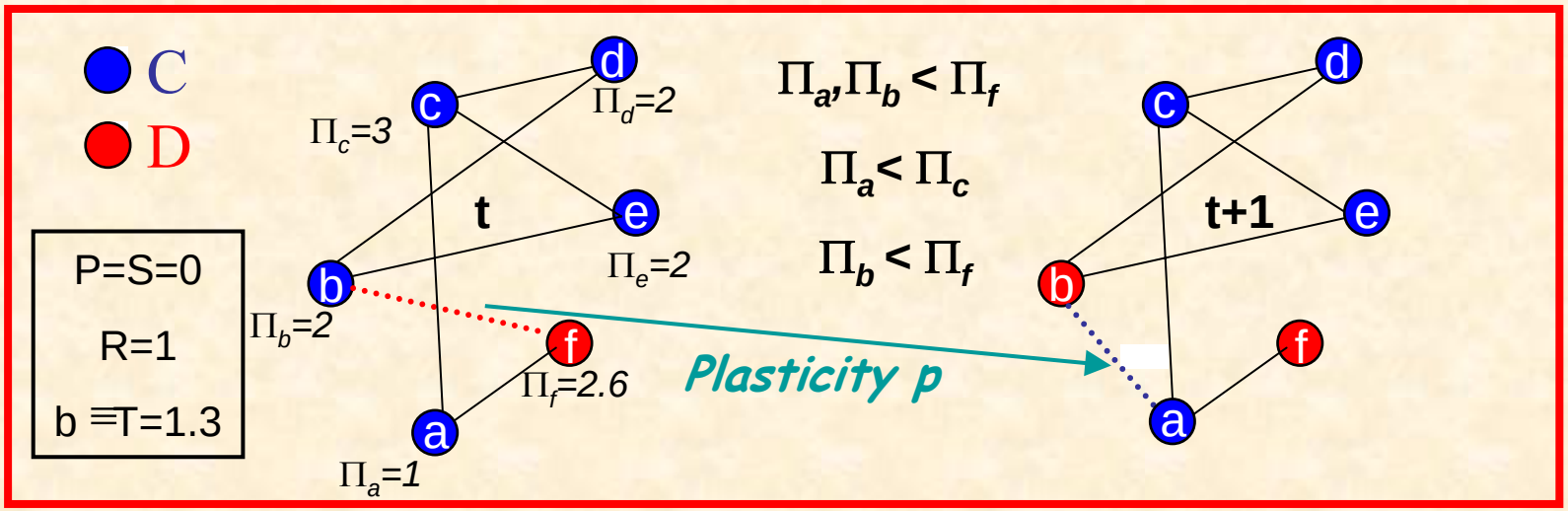
PD game with local interactions and co-evolving network

- Define a random ***network*** *N*, with an average number of links per site *K*.
- Each agent *i* plays a PD game with ***all*** its neighbors using the ***same action*** $s_i \in \{C,D\}$, and collects a total payoff Π_i.
- **Action update:** Each player *i* ***imitates*** the strategy of its neighbor (including himself) with the largest payoff, *l(i)*. Player *i* is **satisfied** if $i = l(i)$; otherwise **unsatisfied**

$$s_i(t+1)=s_{l(i)}(t)$$ ***IMITATION BY SUCCESS***

- **Network Dynamics (Choosing partners): If** player *i* is an **unsatisfied** D-agent, it breaks **with probability *p*** any link with other D-neighbour and establishes randomly new links in the network.

EXIT FROM UNSATISFACTORY RELATION



Steady states

Actions (strategies) and network (links) do not change:

•All C-network is a steady state

•However an All D-network is NOT a steady state for $p \neq 0$

Conditions for a non-trivial steady state:

i) No links between D-agents so that *Network Dynamics* does not occur.

ii) If C-agent i interacts with D-agent d, $\Pi_{l(i)} > \Pi_d > \Pi_i$

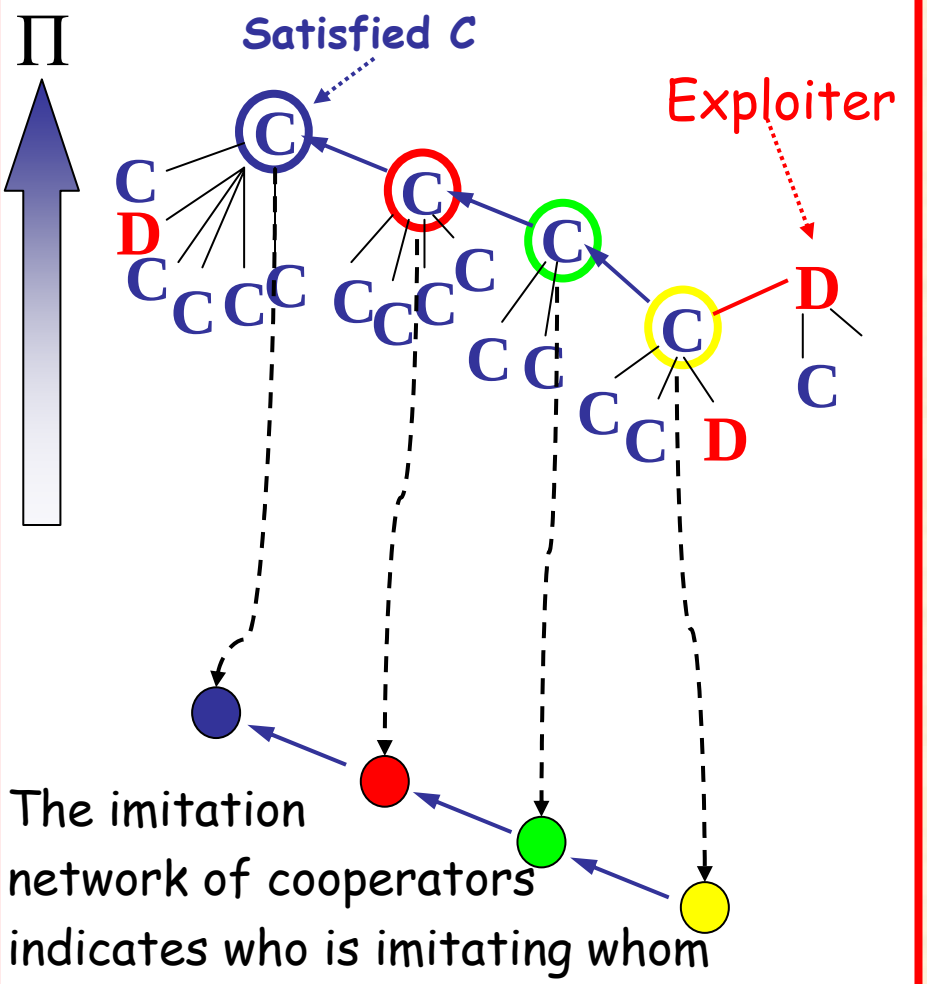
- *Chain of cooperators:* C-agents must imitate other C-agents (most C-agents are Conformists).
- *D-agents have to be passive* local maxima (Exploiters), so that their strategy is not imitated.

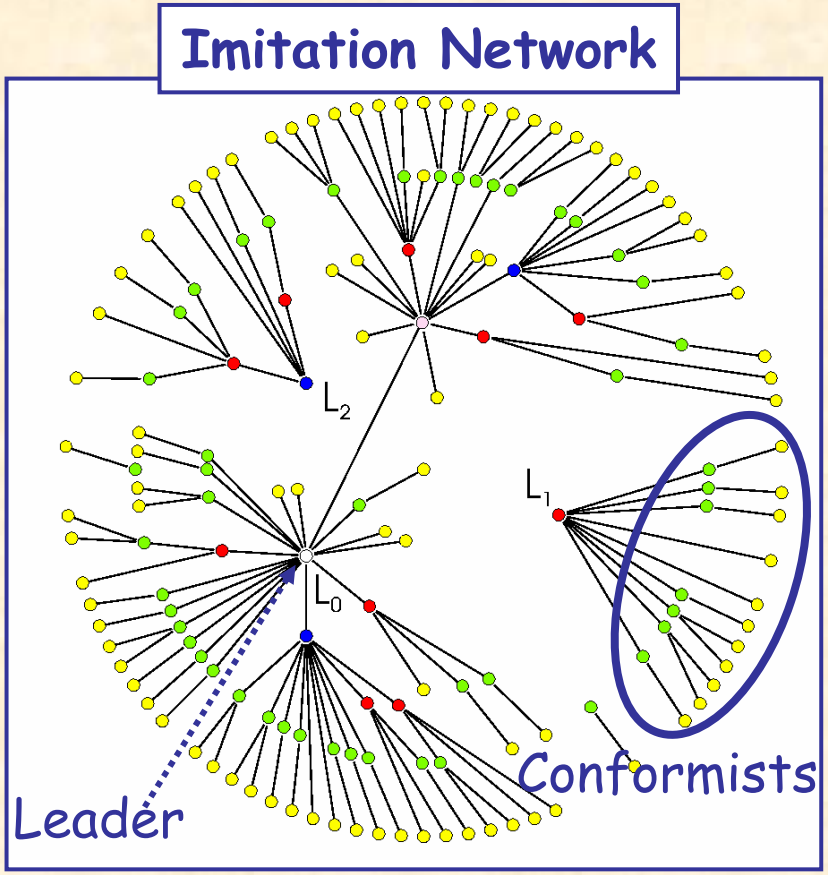
SOCIAL DIFFERENTIATION:

Leaders, Conformists, Exploiters

Leaders: Satisfied C-agents with maximum pay-off in the chain

Hierarchical Network



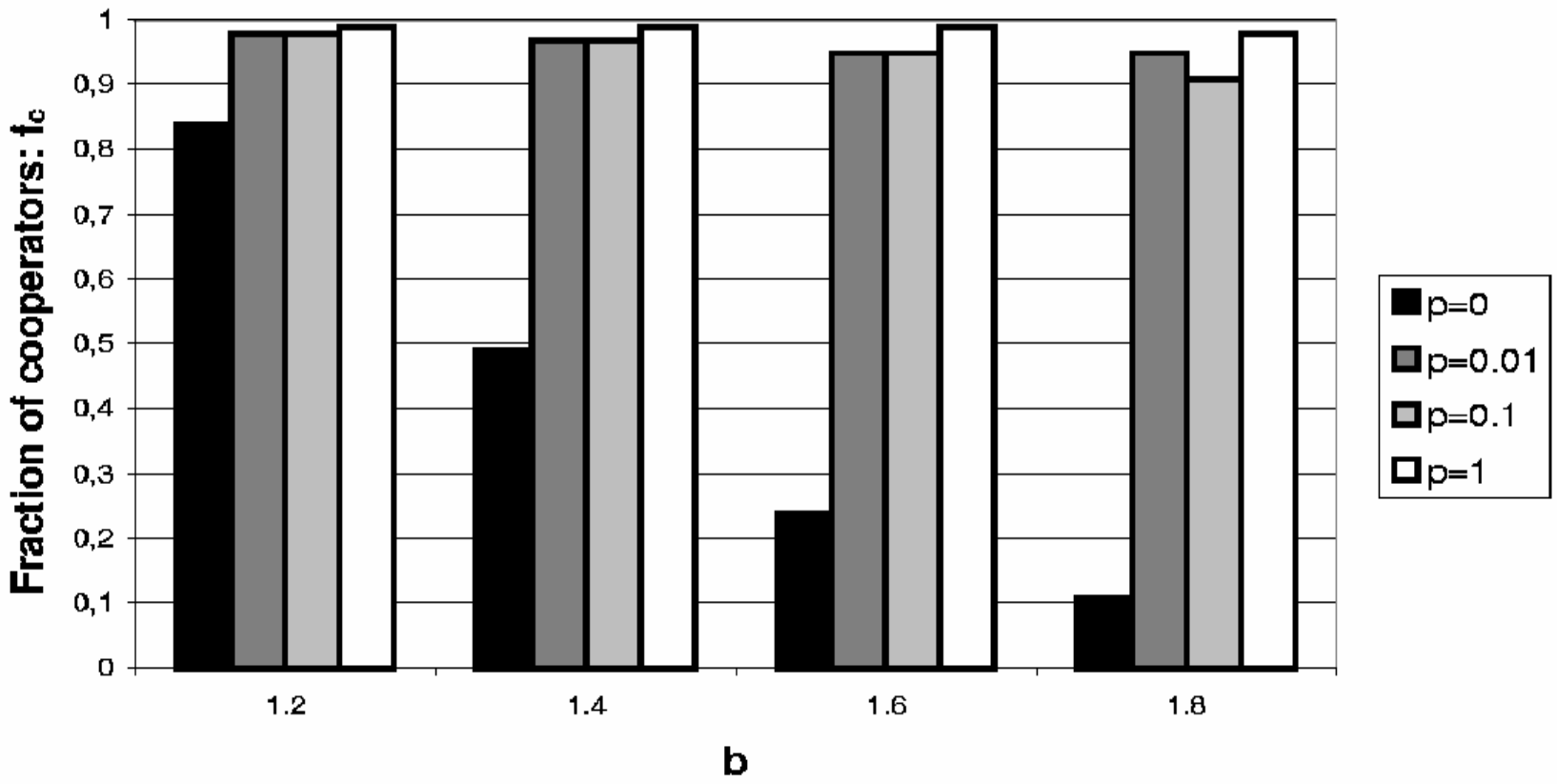


L_0: **absolute leader** with maximum payoff and largest number of links

L_1, L_2 are leaders (satisfied *C*) with a payoff lower than the absolute leader.

Role differentiation, including spontaneous leader selection, emerges from stochastic dynamics of initially equivalent agents

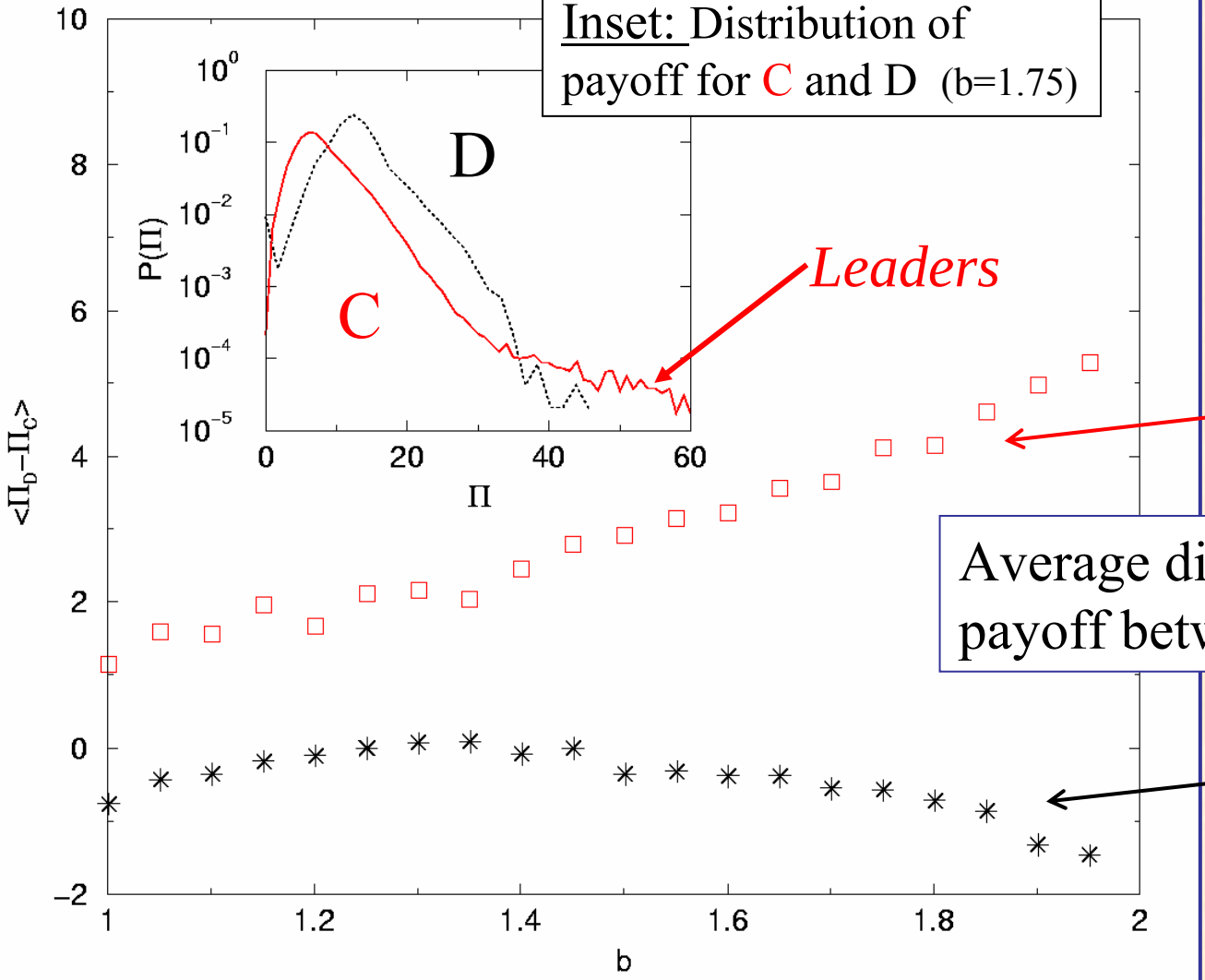
Fraction of cooperators



N=10,000 Averages over 100 runs

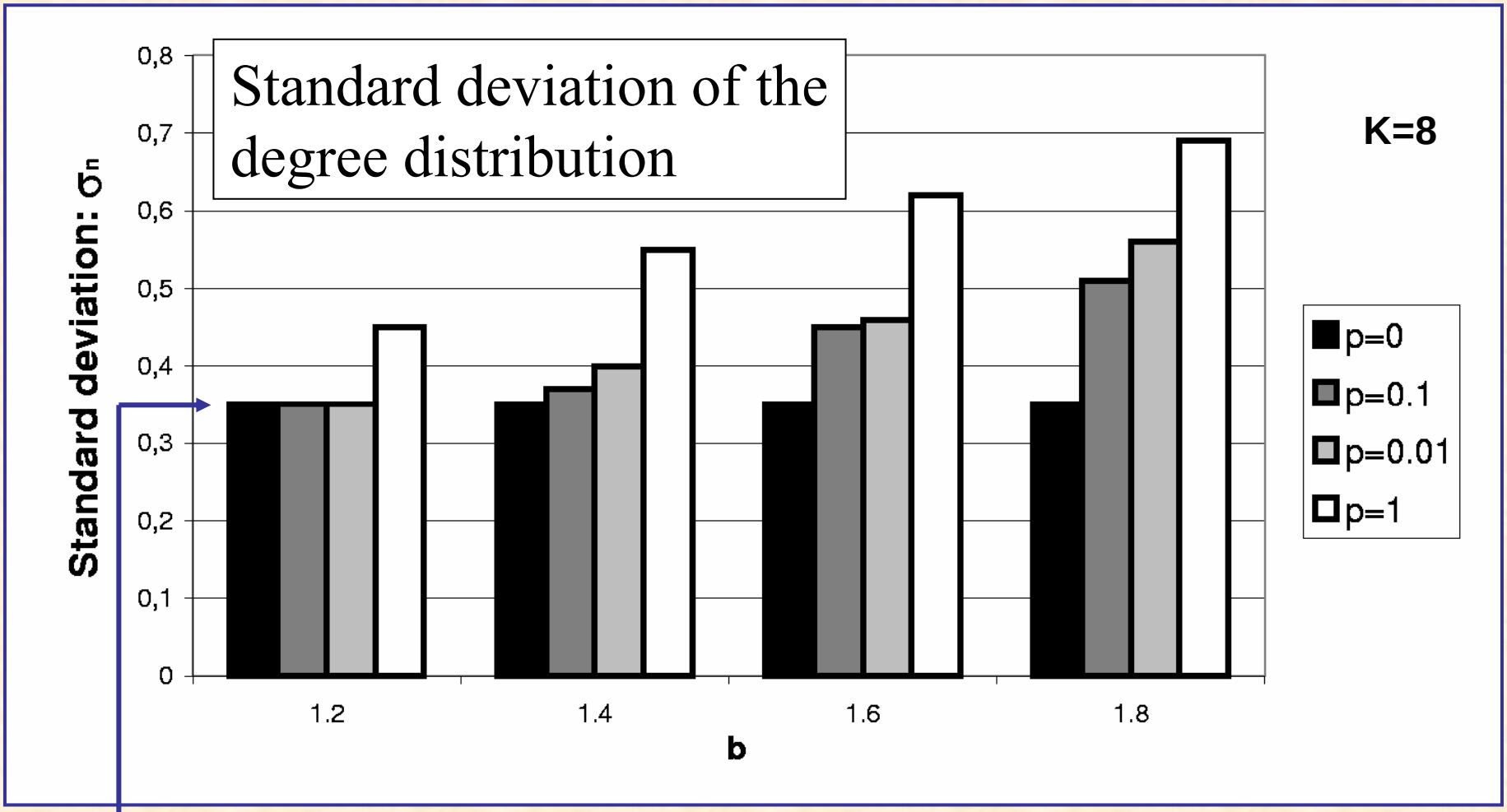
Initial condition: 60% C, random network K=8

Wealth distribution



There are less Defectors but they get richer.

Structure of the social network

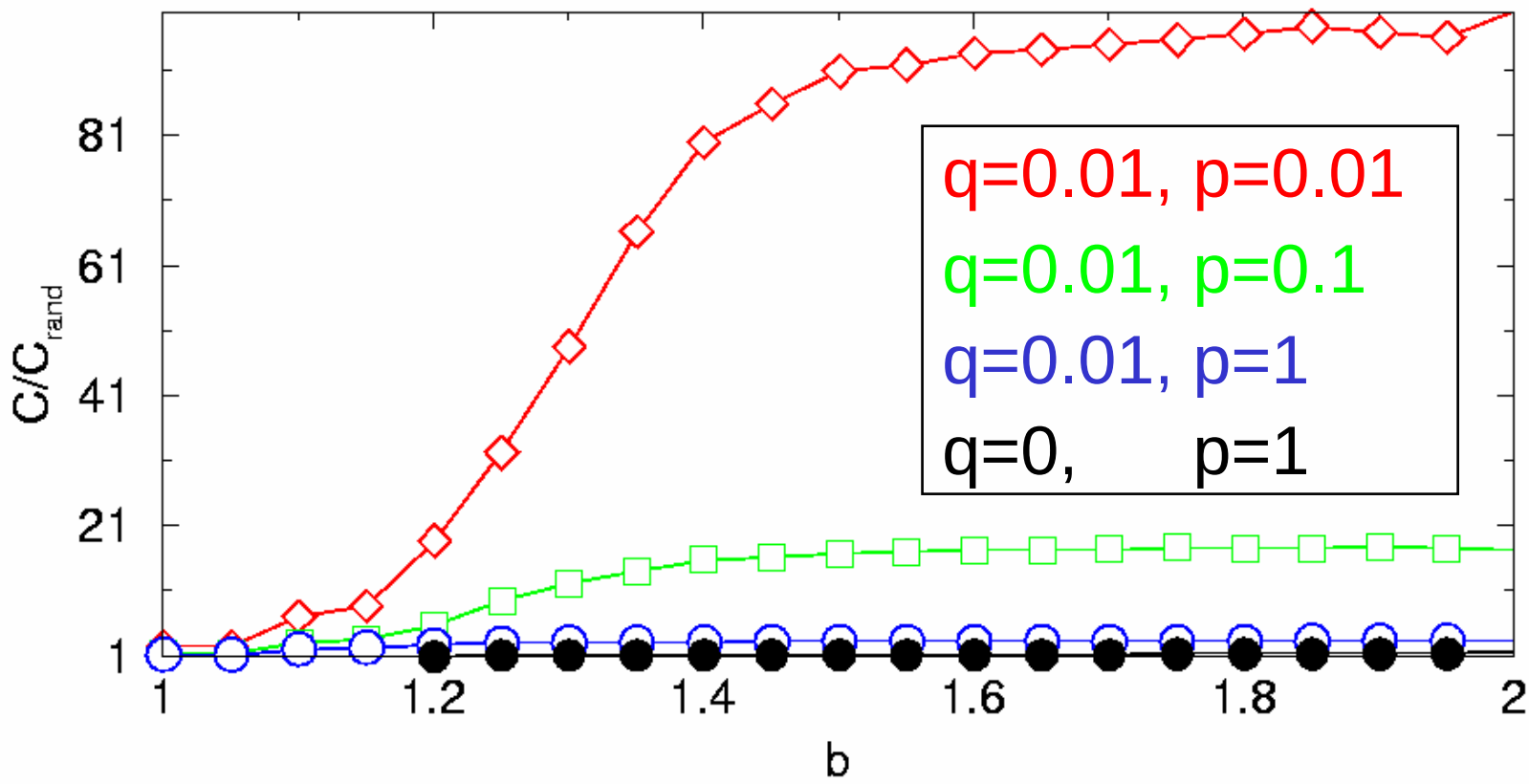


Poisson distribution

σ_n= 1: Exponential

Gini coefficient: The social dynamics generates a flux of pay-off towards richer individuals

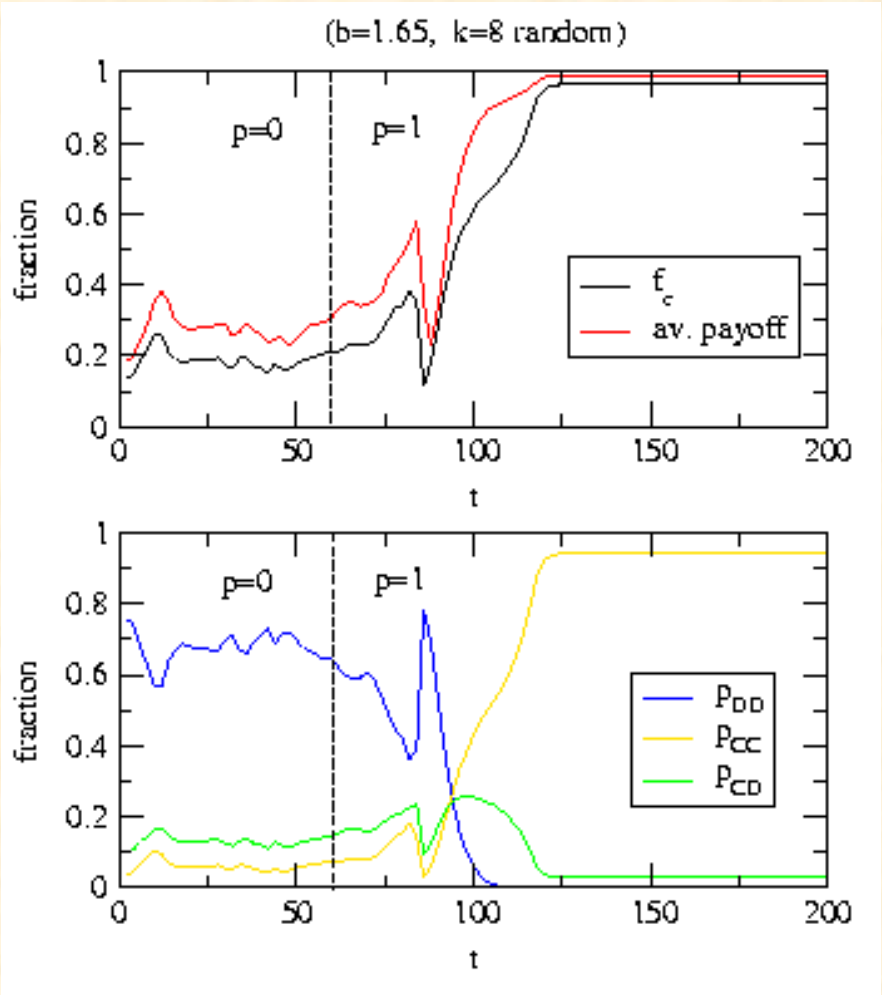
Clustering

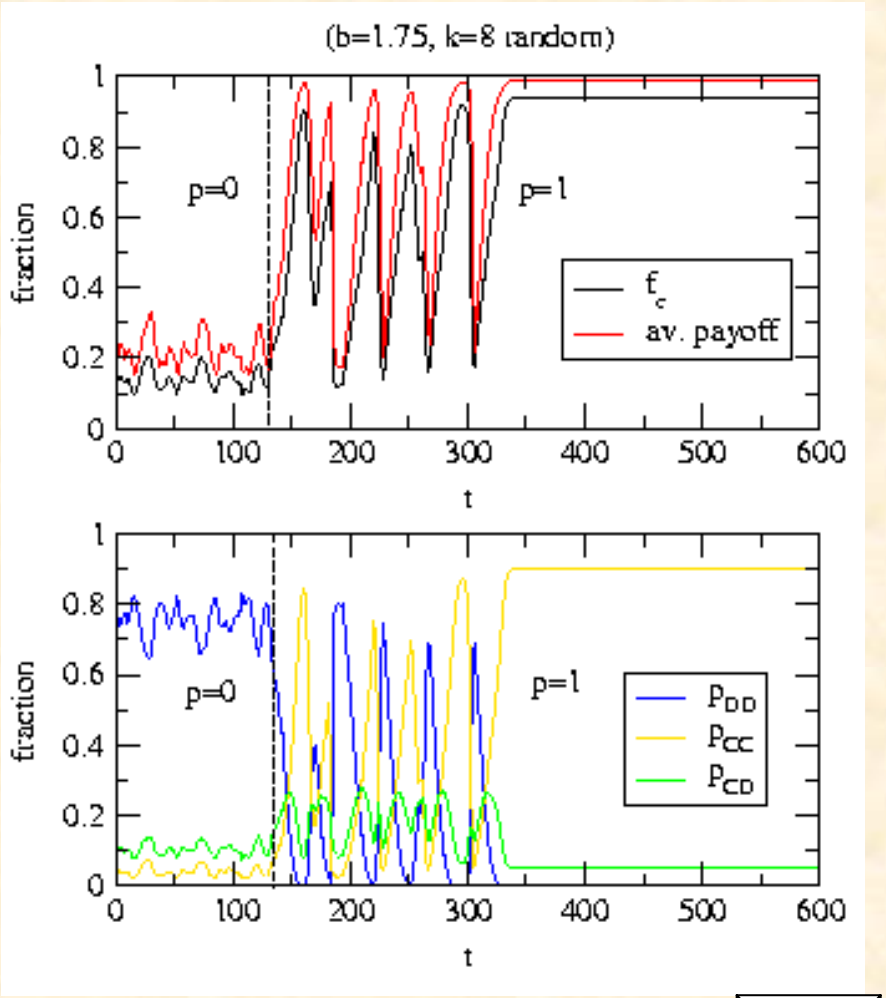


q= probability that new partner is selected among neighbors of the neighbors

Small World connectivity emerges if local partner selection is allowed

Network evolution and large oscillations

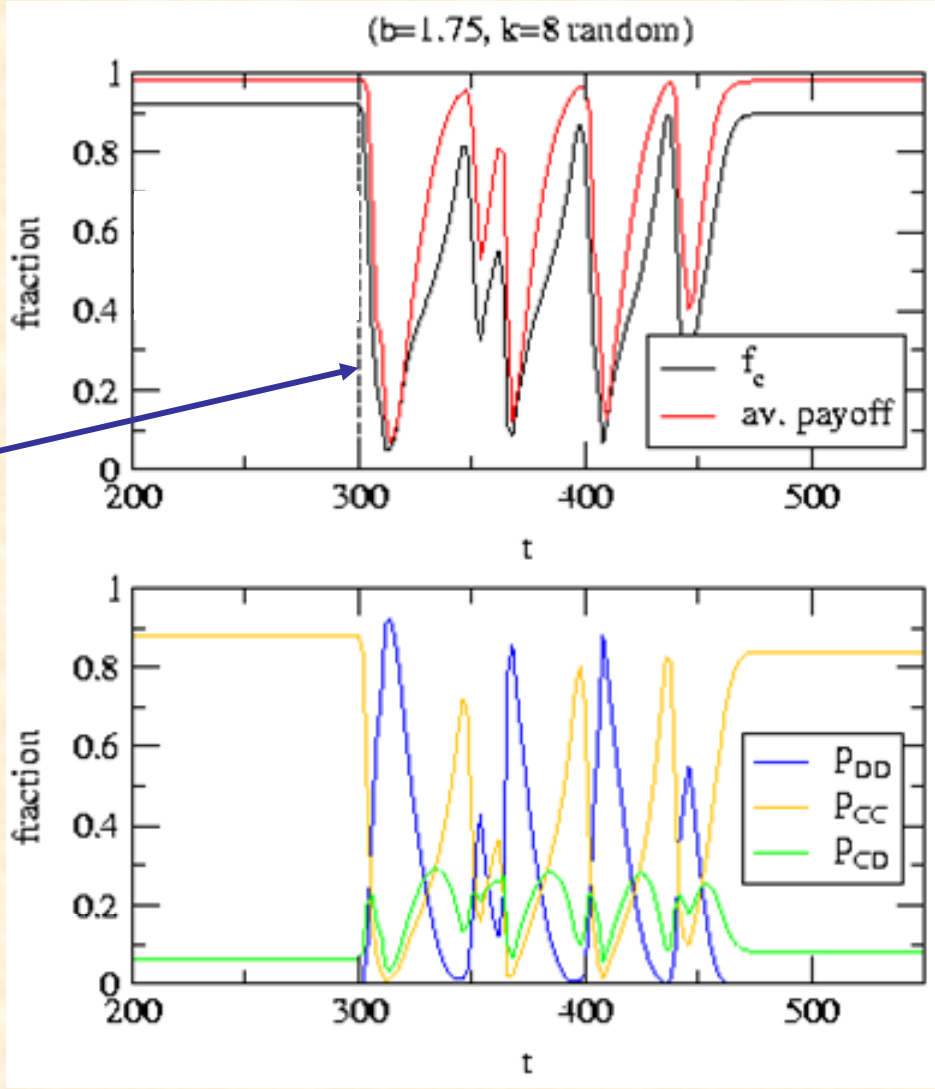




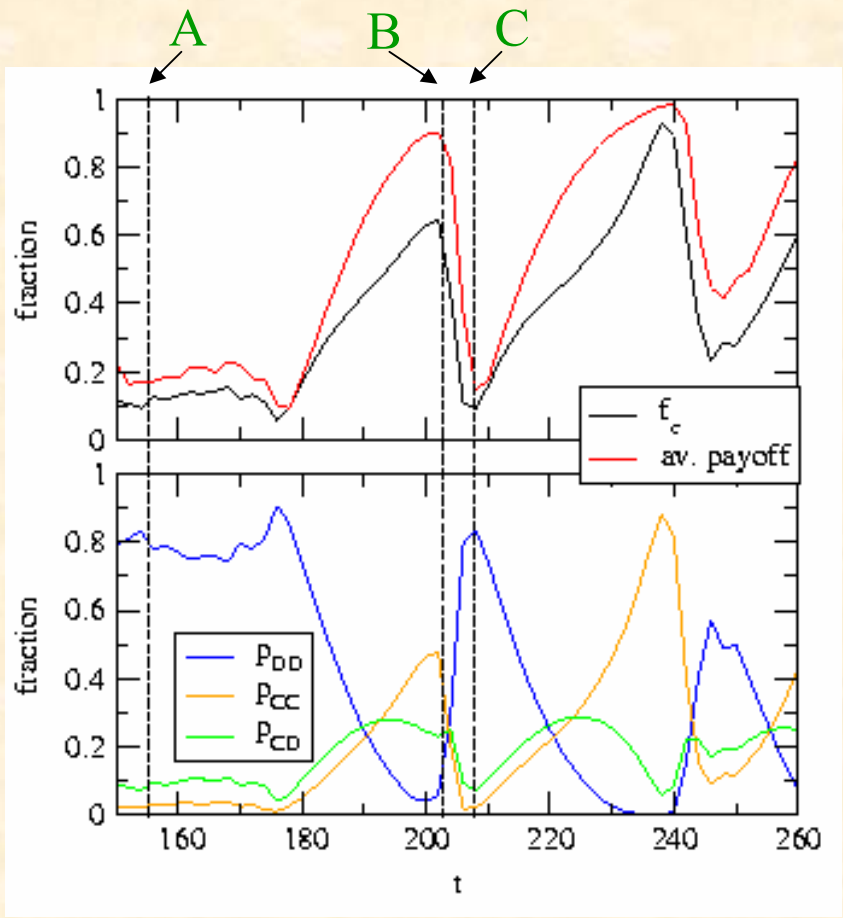
For high enough b, large transient oscillations occur

Social Crisis

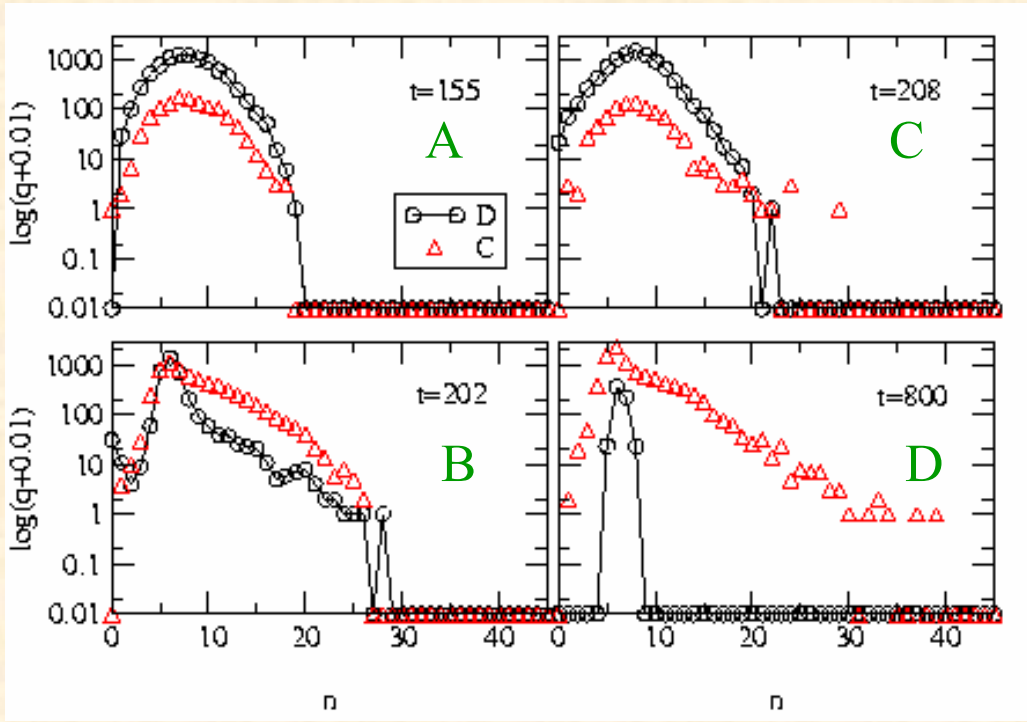
Perturbation
C ⟶ D
acting on the
leader



Large Oscillations



Links histograms



A, C: **Gaussian** D: **final state**

B: **Exponential**

Conclusions

Structure of network is both cause and consequence of successful cooperation (Macy, 1991)

•Co-evolution (social plasticity) leads to:

> a highly ***cooperative*** steady state.

> the emergence of ***social roles***: **leaders, conformists and exploiters.**

> hierarchical social networks with exponential tails in the connectivity and wealth distribution.

•Perturbations to leaders trigger large cascades (***social crisis***).

•A ***small world*** network can be obtained if we allow for local *partner selection.*