DOES NETWORK RECIPROCITY PROMOTE COOPERATION?

- EXPERIMENTS WITH HUMAN SUBJECTS -

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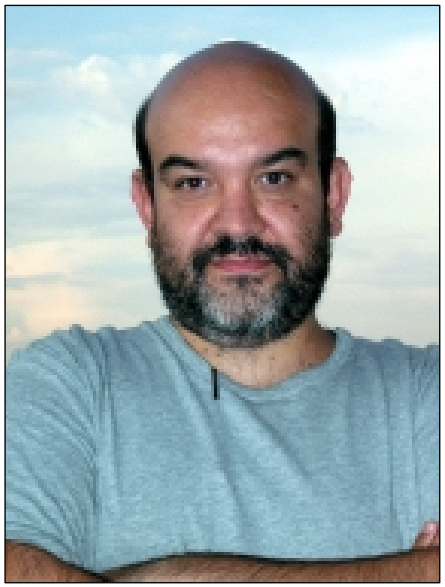
Grupo Interdisciplinar de Sistemas Complejos

Anxo Sánchez



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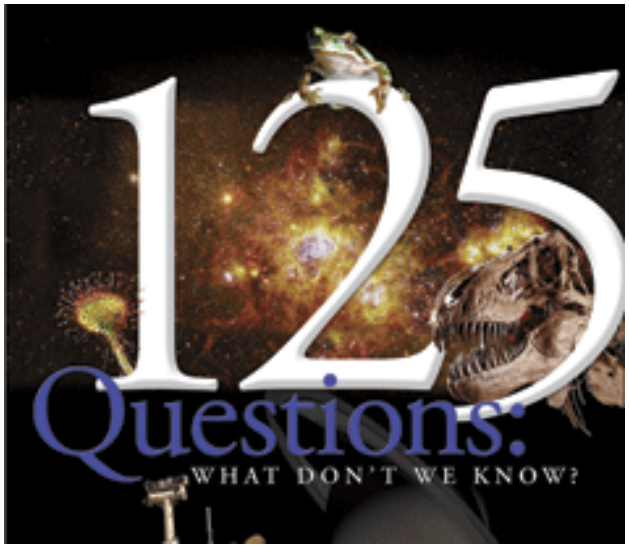
THE PUZZLE OF COOPERATION

- Charles Darwin (1896): “If it could be proved that any part of the structure of any one species had been formed for the exclusive good of another species**, it would annihilate my theory**, for such could not have been produced through natural selection.”

- Robert May (2005): “**The most important unanswered question in evolutionary biology**, and more generally in the social sciences, is how cooperative behavior evolved and can be maintained in human or other animal groups and societies”

- Cooperation is costly – lower fitness
- Defectors more likely to evolve
- However, it is everywhere
  - Genomes
  - Cells
  - Multicellular organisms
  - Human and animal societies



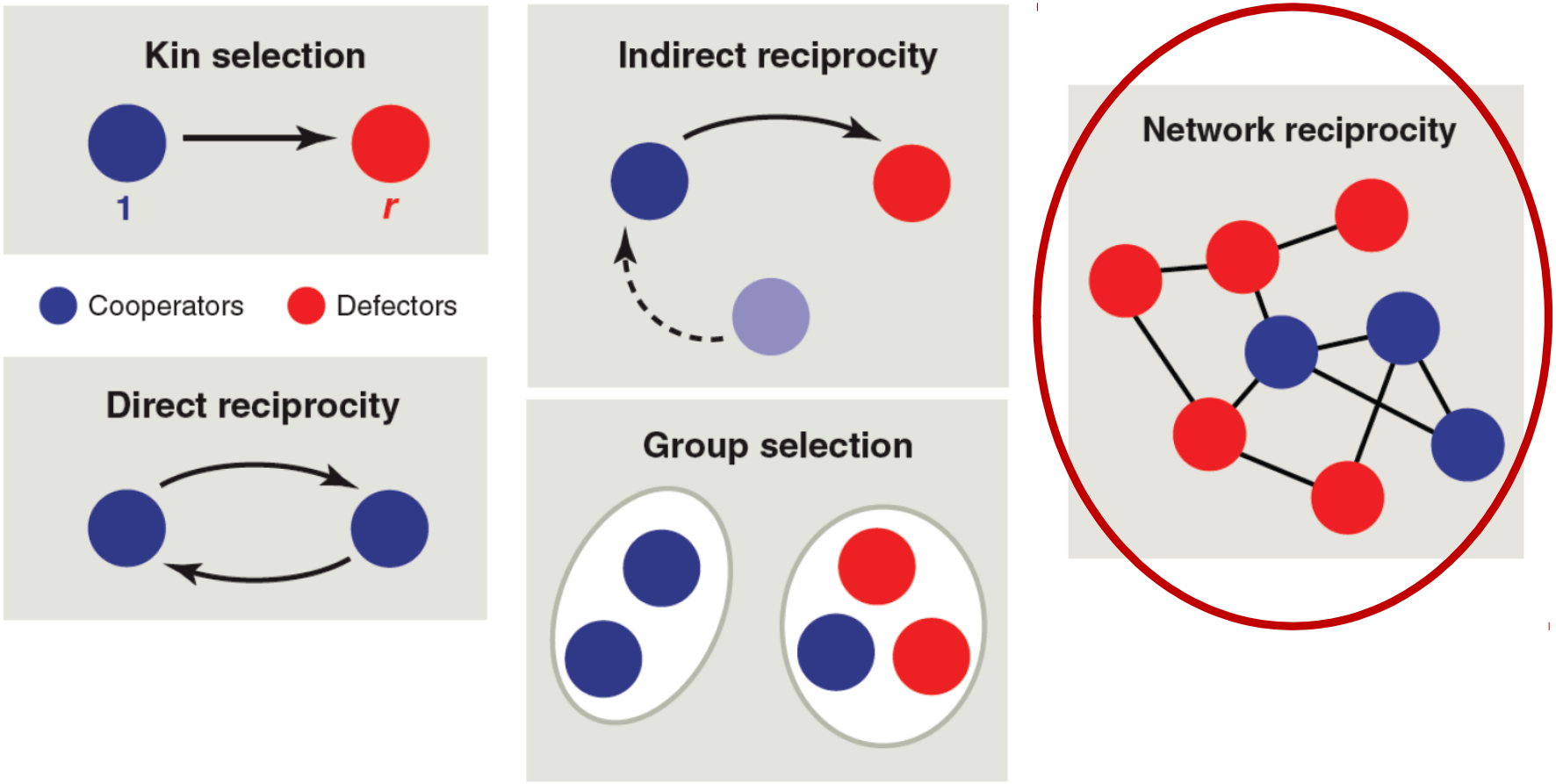
PRISONER'S DILEMMA

	C	D
C	**R**, R	**S**, T
D	**T**, S	**P**, P

$$T > R > P \geq S$$

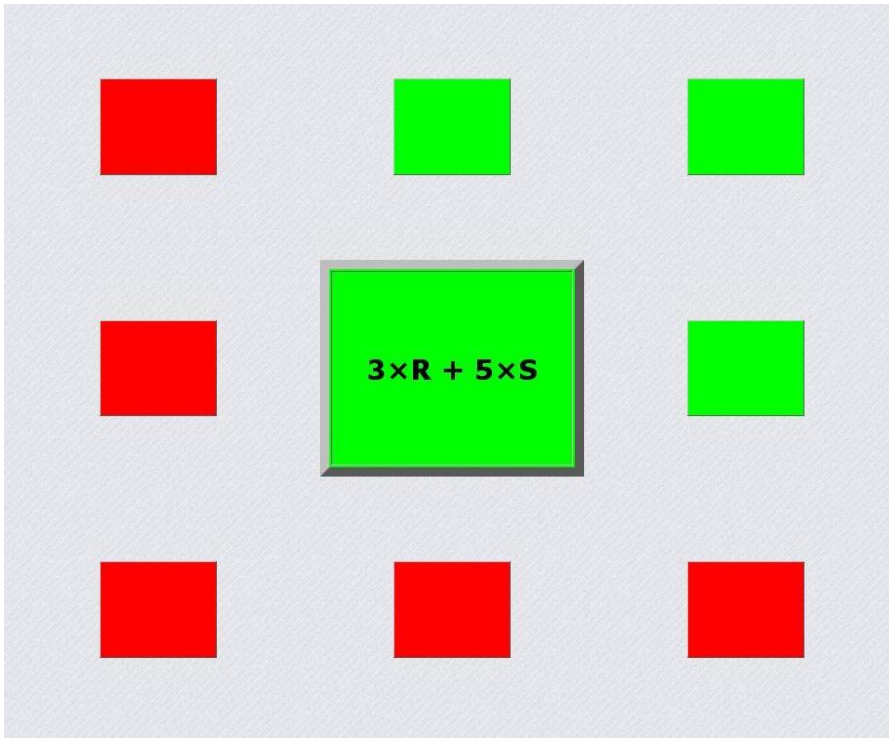
- **T**emptation to defect
- **R**eward for mutual cooperation
- **P**unishment for mutual defection
- **S**ucker's payoff
- For iterated: $T + S < 2R$

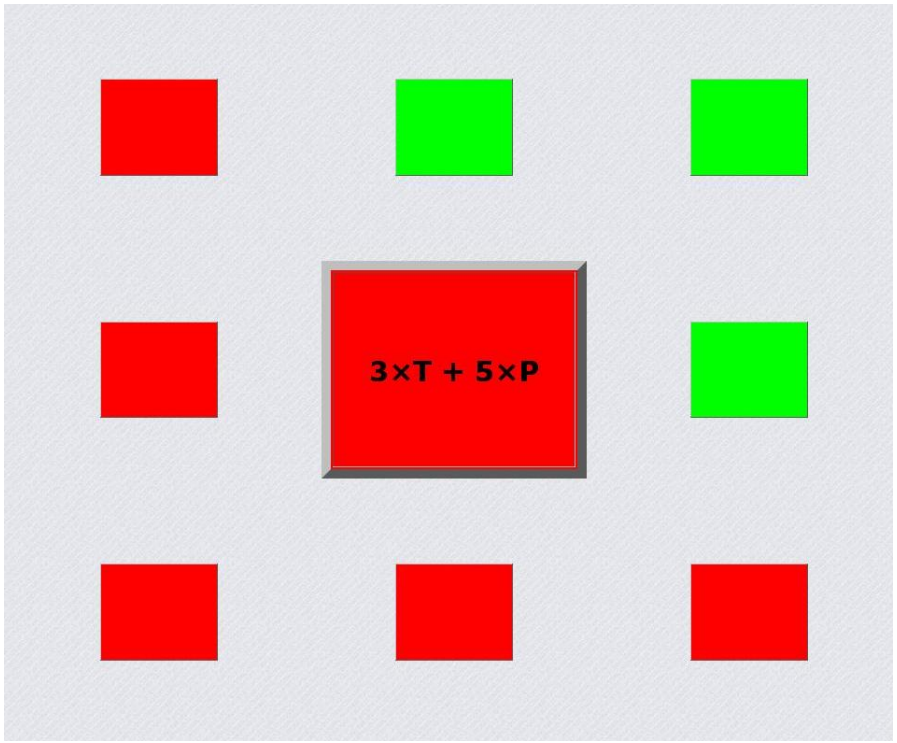
FIVE RULES FOR THE EVOLUTION OF COOPERATION



Nowak, *Science* (2006)

SPATIAL GAMES

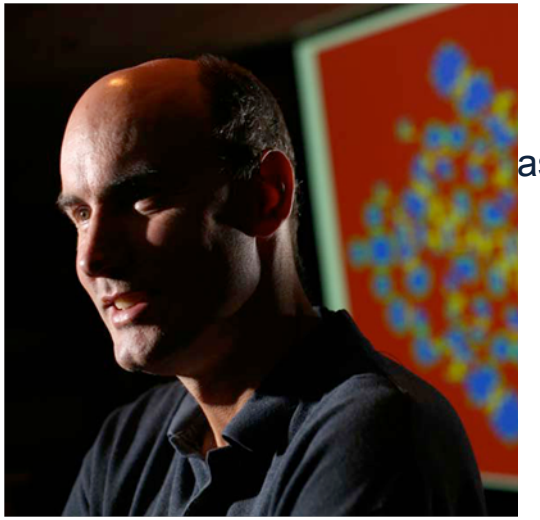




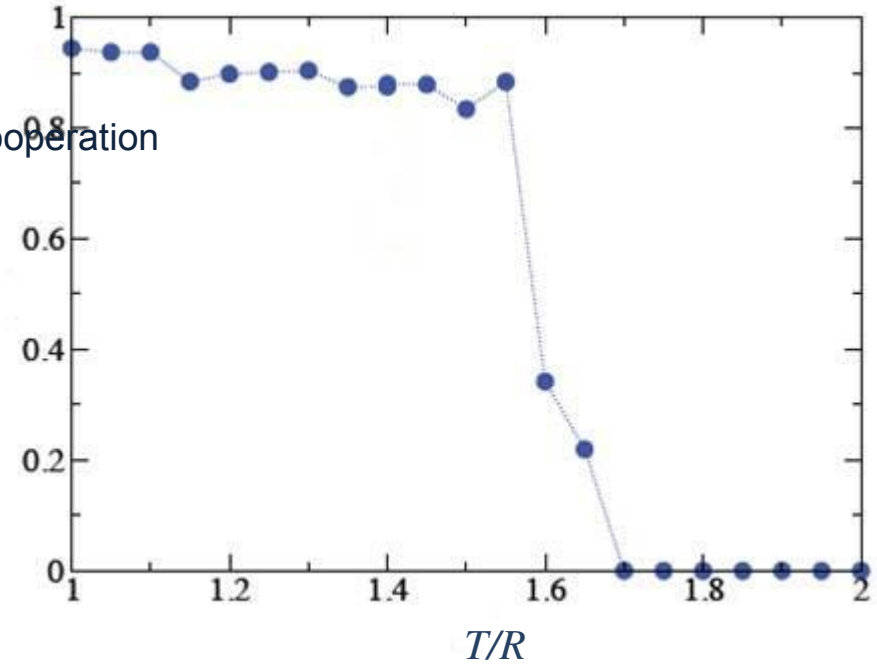
Cooperate

Defect

M.A. NOWAK AND R.M. MAY, *NATURE* 359, 826 (1992)

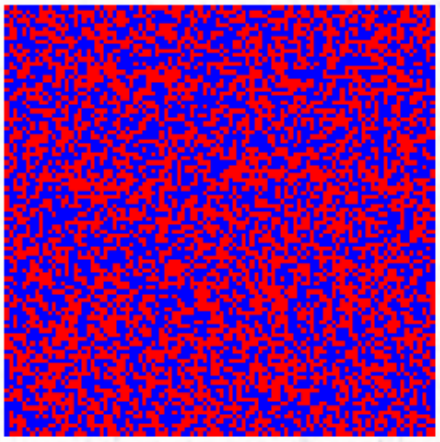


asymptotic cooperation



Unconditional imitation – copying the best neighbor

CLUSTERS



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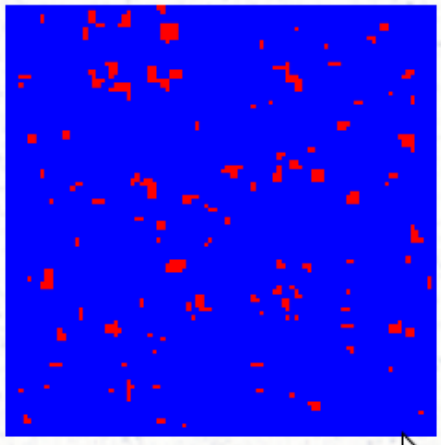

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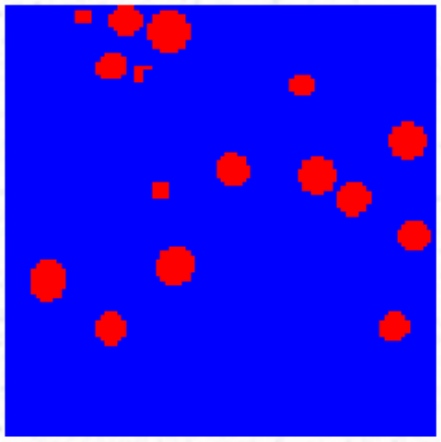

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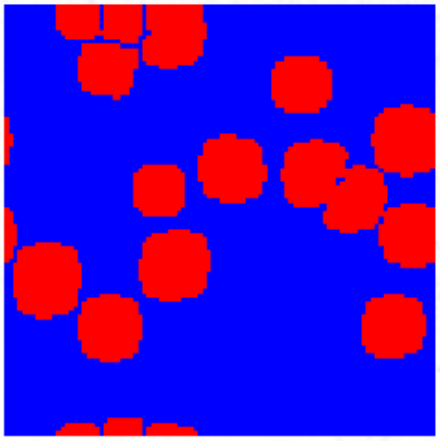

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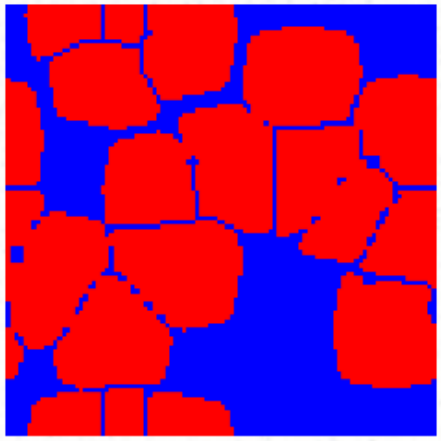

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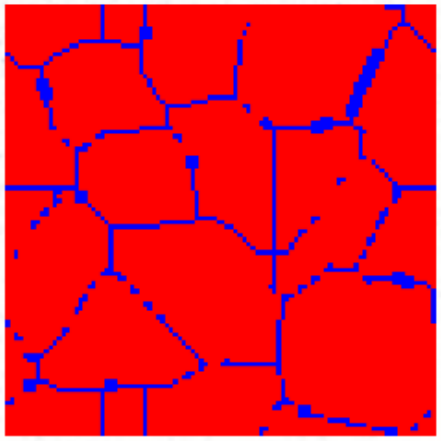
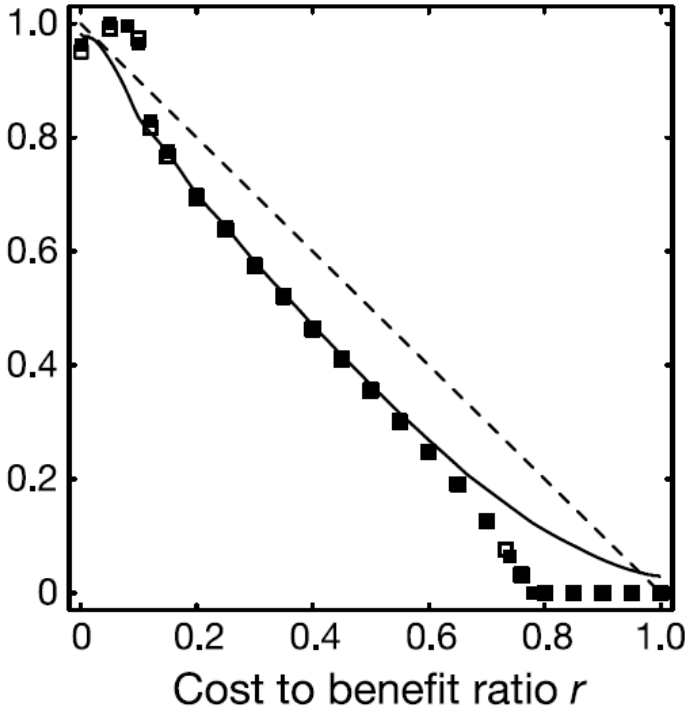


t = 35

HAUERT AND DOEBELI, NATURE (2004)

- Snowdrift game
- Two drivers trapped on opposite sides of snowdrift
- T > R > S > P
- No promotion of cooperation!



PROMOTES COOPERATION OR NOT!?

- It is the update mechanism
- Replicator rule – the higher the payoff the higher the chance of imitation
- Roca et al. *Phys. Life Rev.* (2009)
- Theoretical work not conclusive
- Experiments needed!
- Known experiments:
  - Cassar, *Games Econ. Behav.* (2007)
  - Kirchkamp and Nagel, *Games Econ. Behav.* (2007)
  - Traulsen et al., *PNAS* (2010)
- Networks sizes < 18 nodes

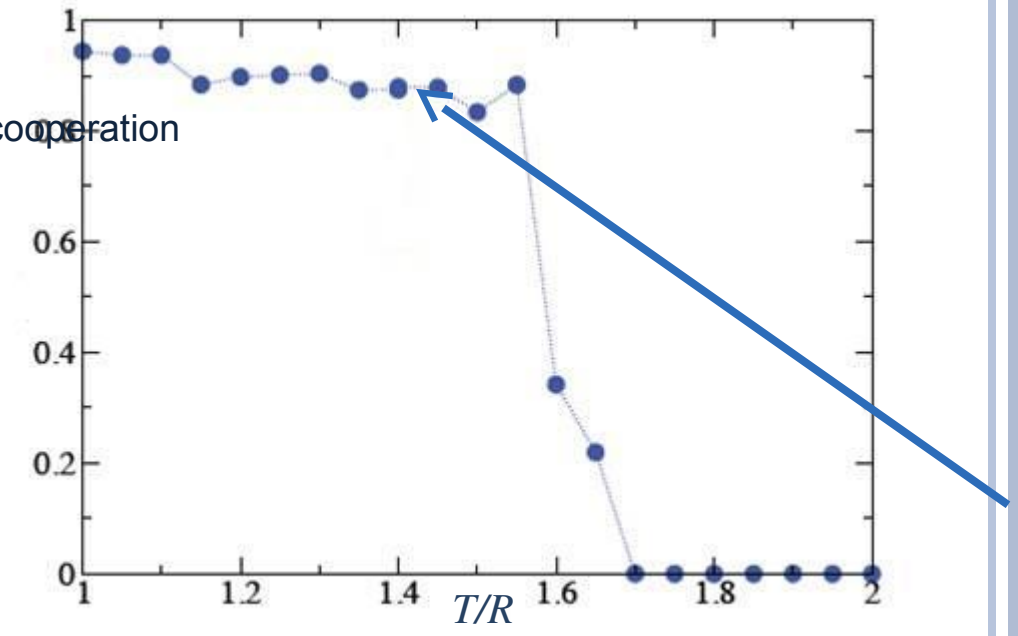
SOFTWARE DEVELOPMENT

- Large experiments are organizationally difficult
- Z-Tree cannot handle 200 users at the same time
- I had to develop a new software for the experiment
- Problems:
  - Local network of 200 machines with special software
  - Concurrency Problems
  - Server overload
- Solutions
  - PHP, javascript – (Opera, Kiosk mode)
  - Background program – Python
  - Parameters of the server
  - Testing with robots

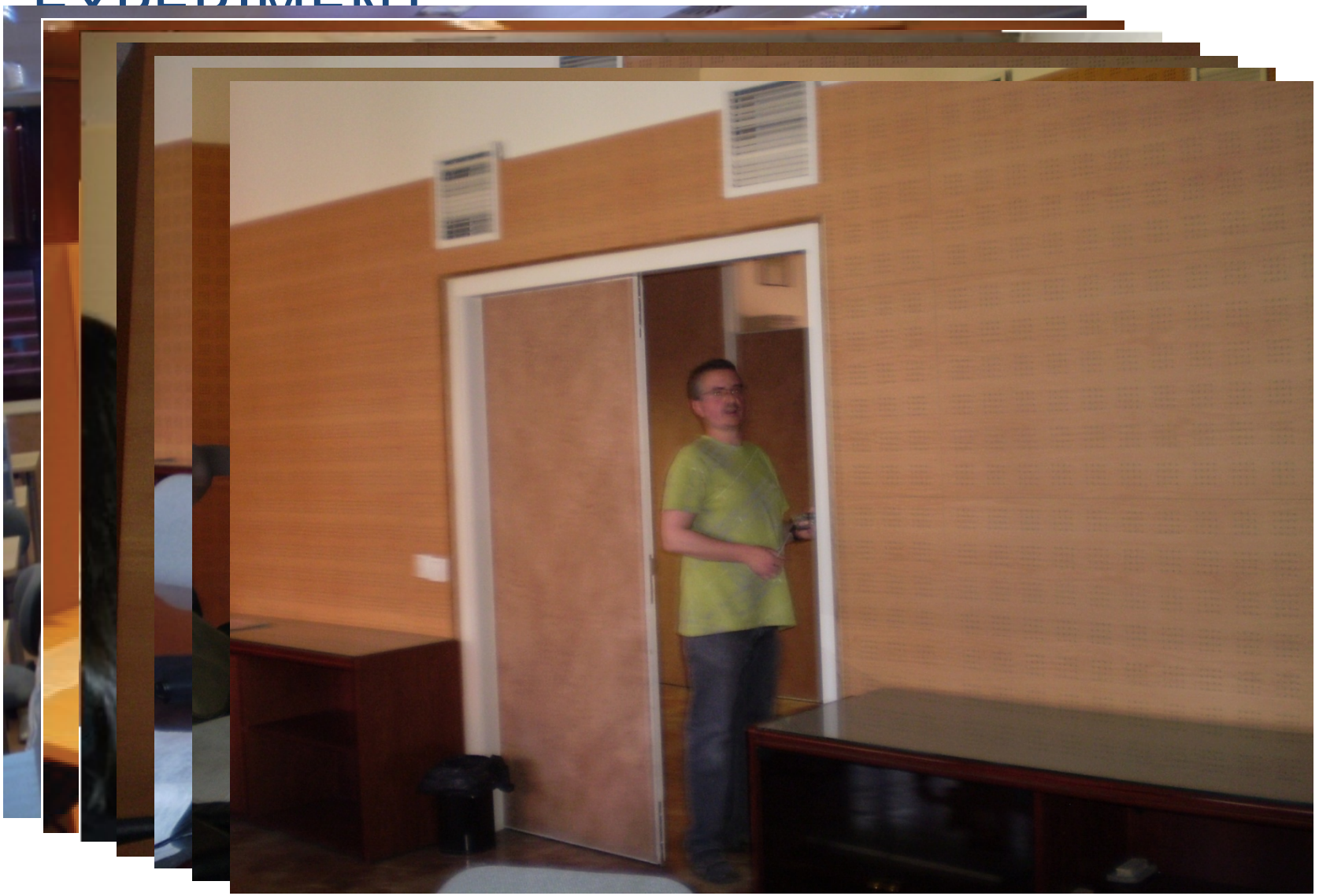
EXPERIMENT

- 169 players
- Undergraduate students UC3M, Campus Leganés
- 40% female, 60% male
- 20 assistants,10 computer rooms, 2 buildings
- From 9 AM till 9 PM

In our Experiment:
T/R = 10/7 ≈1,42857143

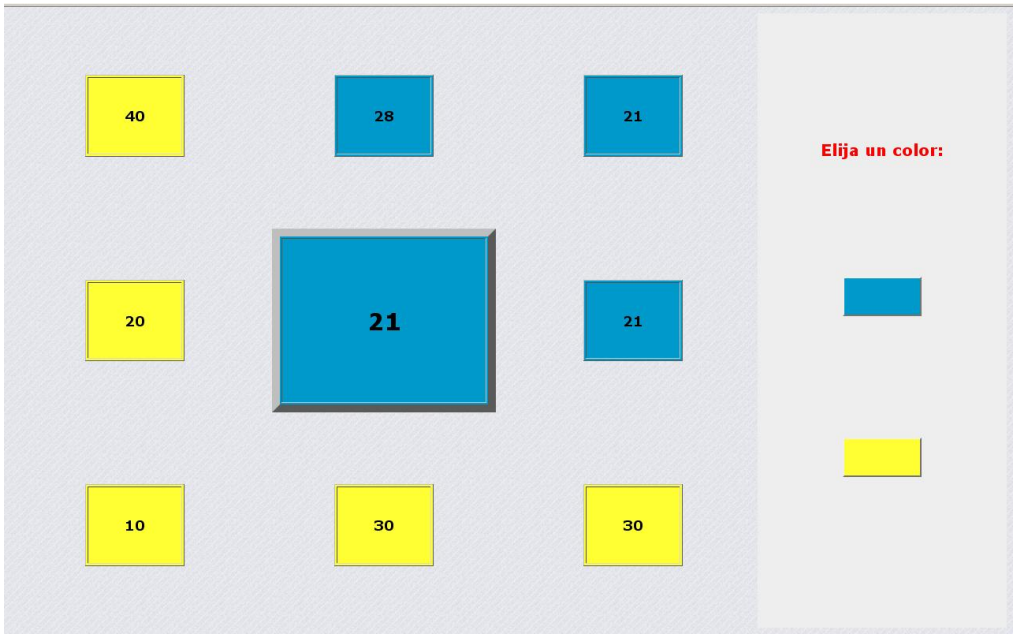


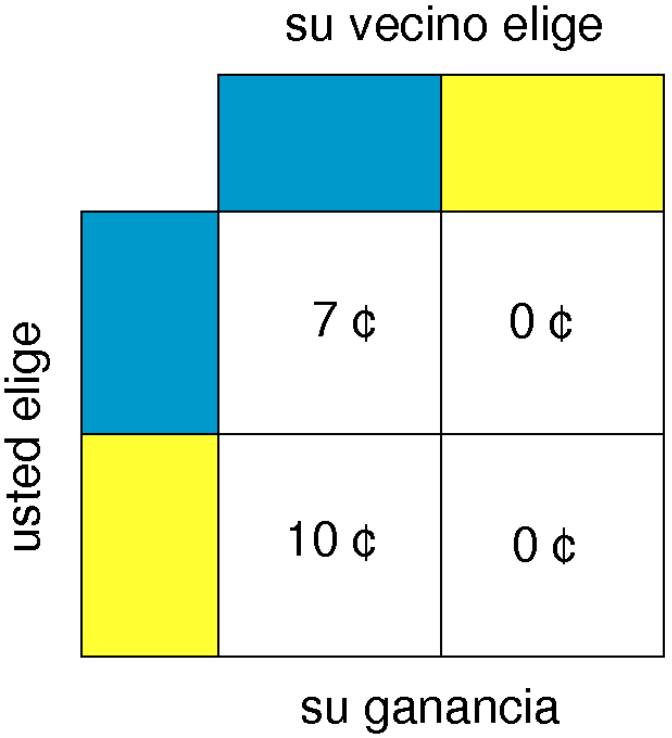
EXPERIMENT



EXPERIMENT

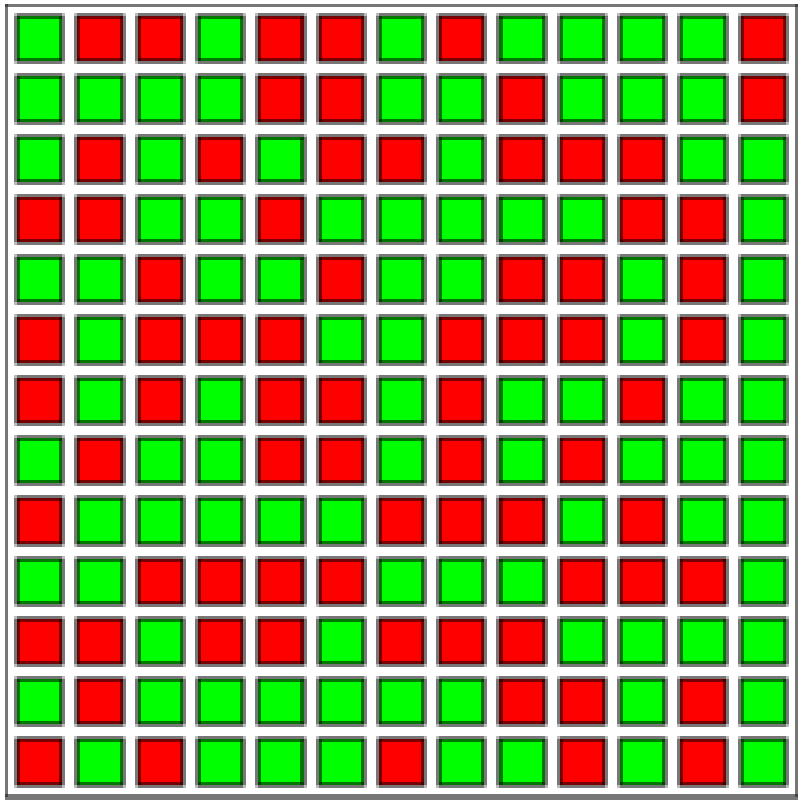
- Lattice 13x13, periodic boundary conditions
- Login → Tutorial → Experiment → Control → Experiment → Questionnaire



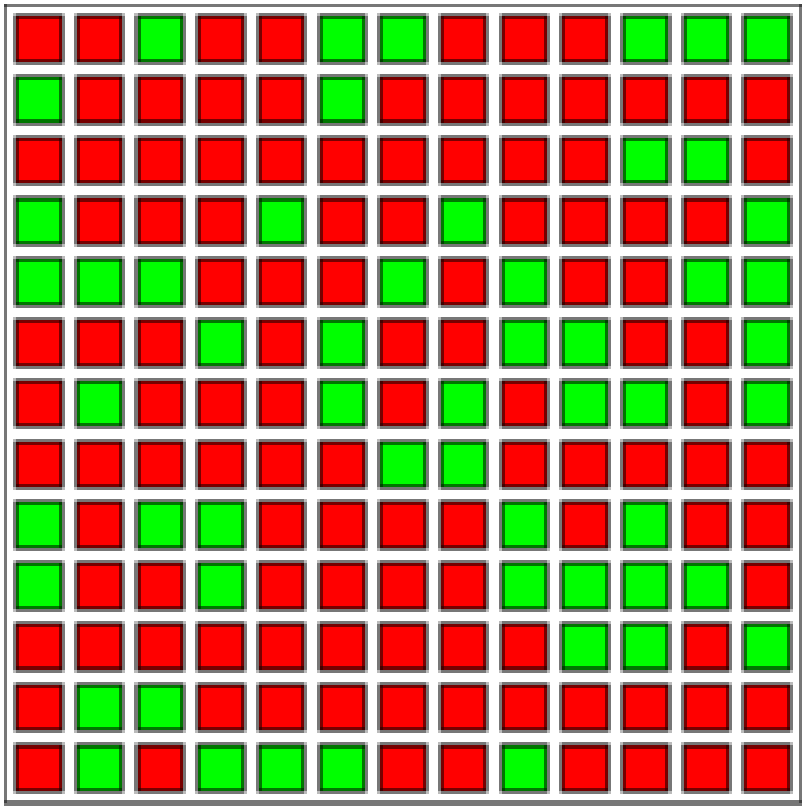


J. Grujić, C. Fosco, L. Araujo, J.A. Cuesta, A. Sánchez, PLoS ONE **5**, e13749 (2010)

MOVIES

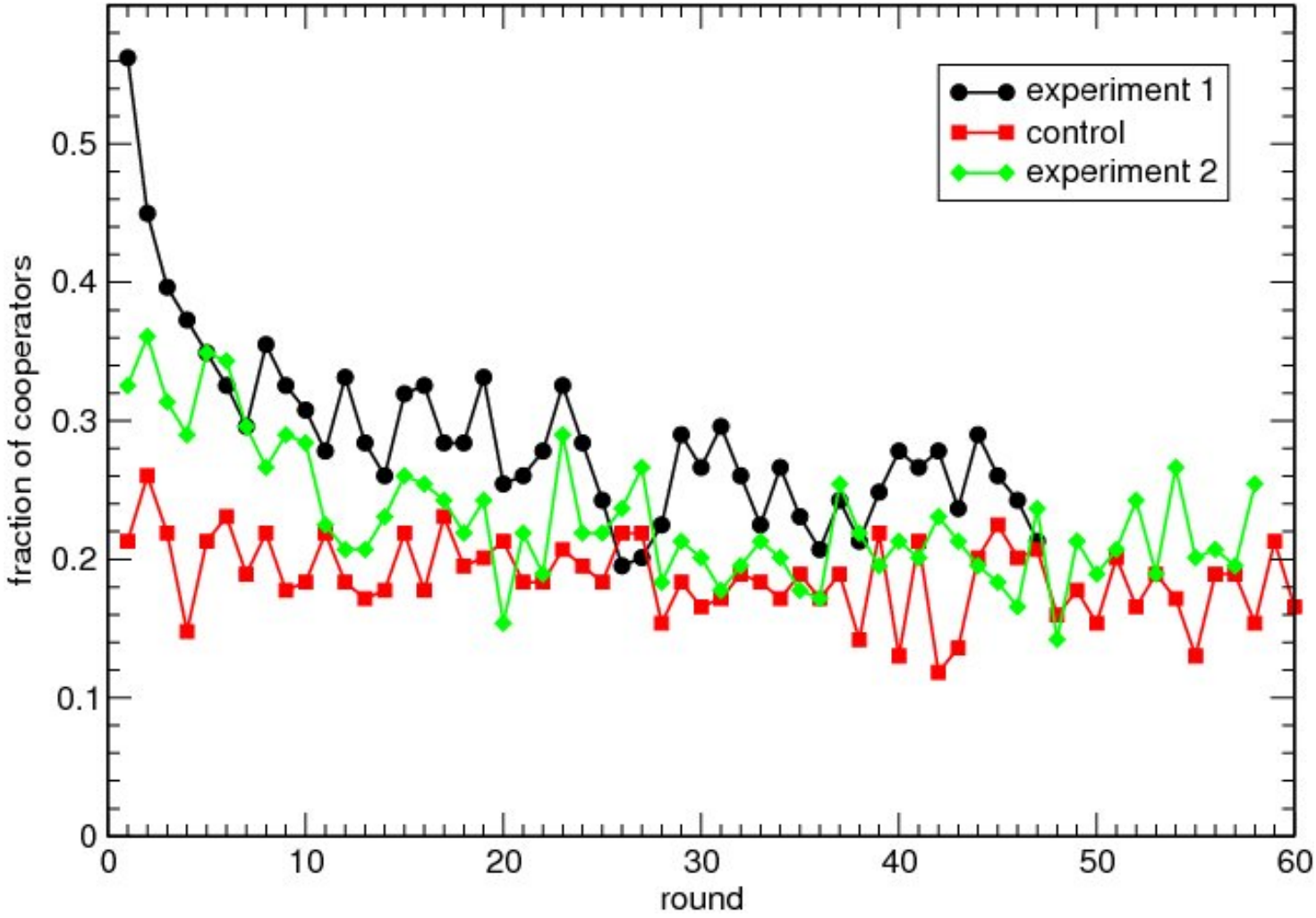


01 of 47

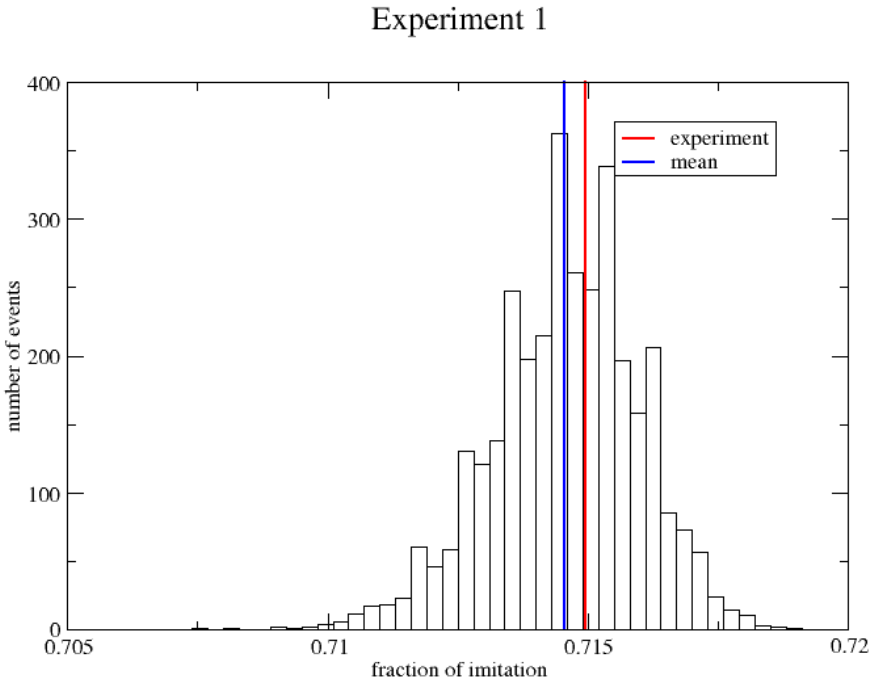


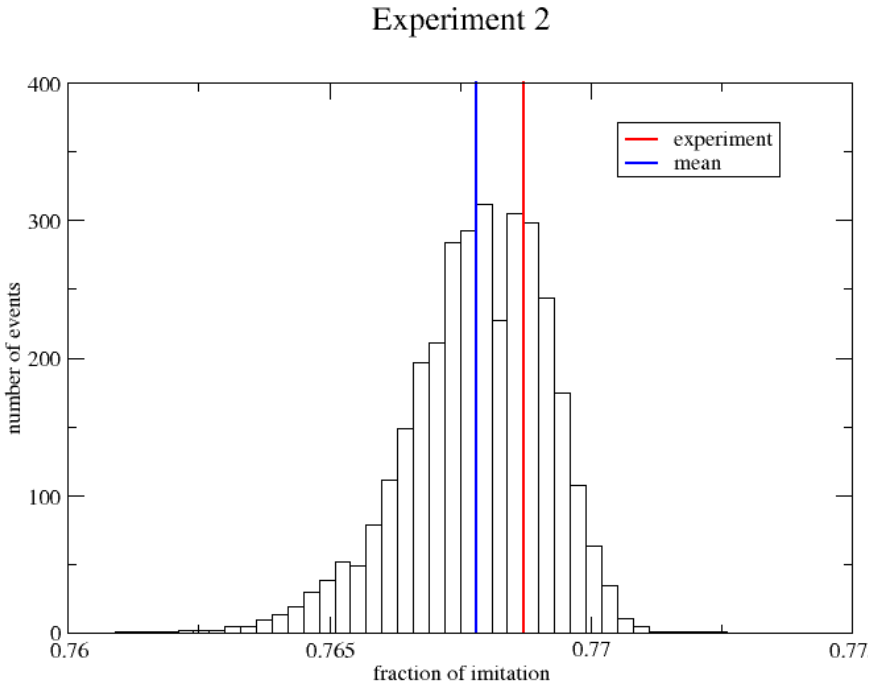
01 of 58

FRACTION OF COOPERATION



UNCONDITIONAL IMITATION

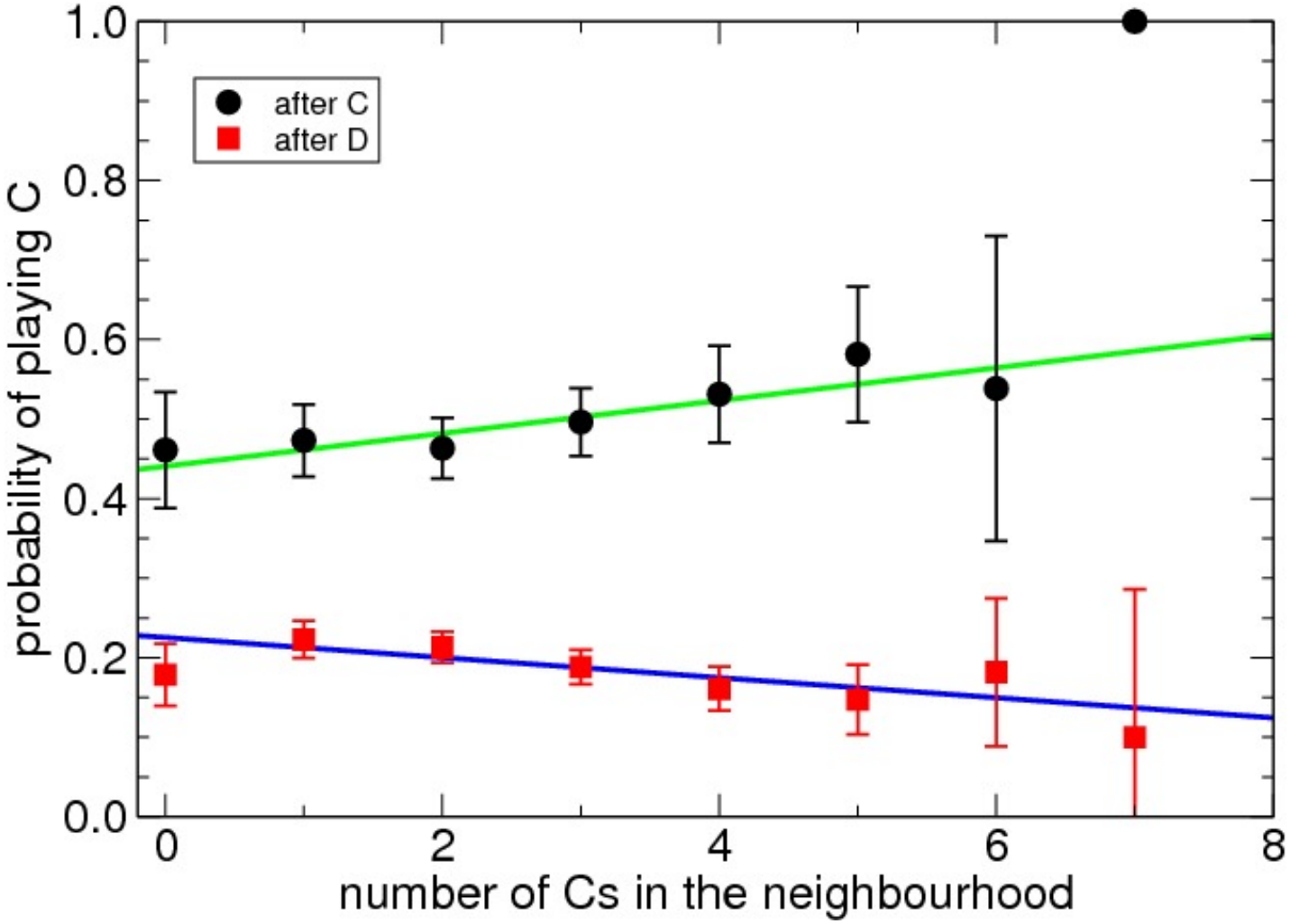




experimental = 0.7149
random = 0.7145 ± 0.0014
p-test = 0.425

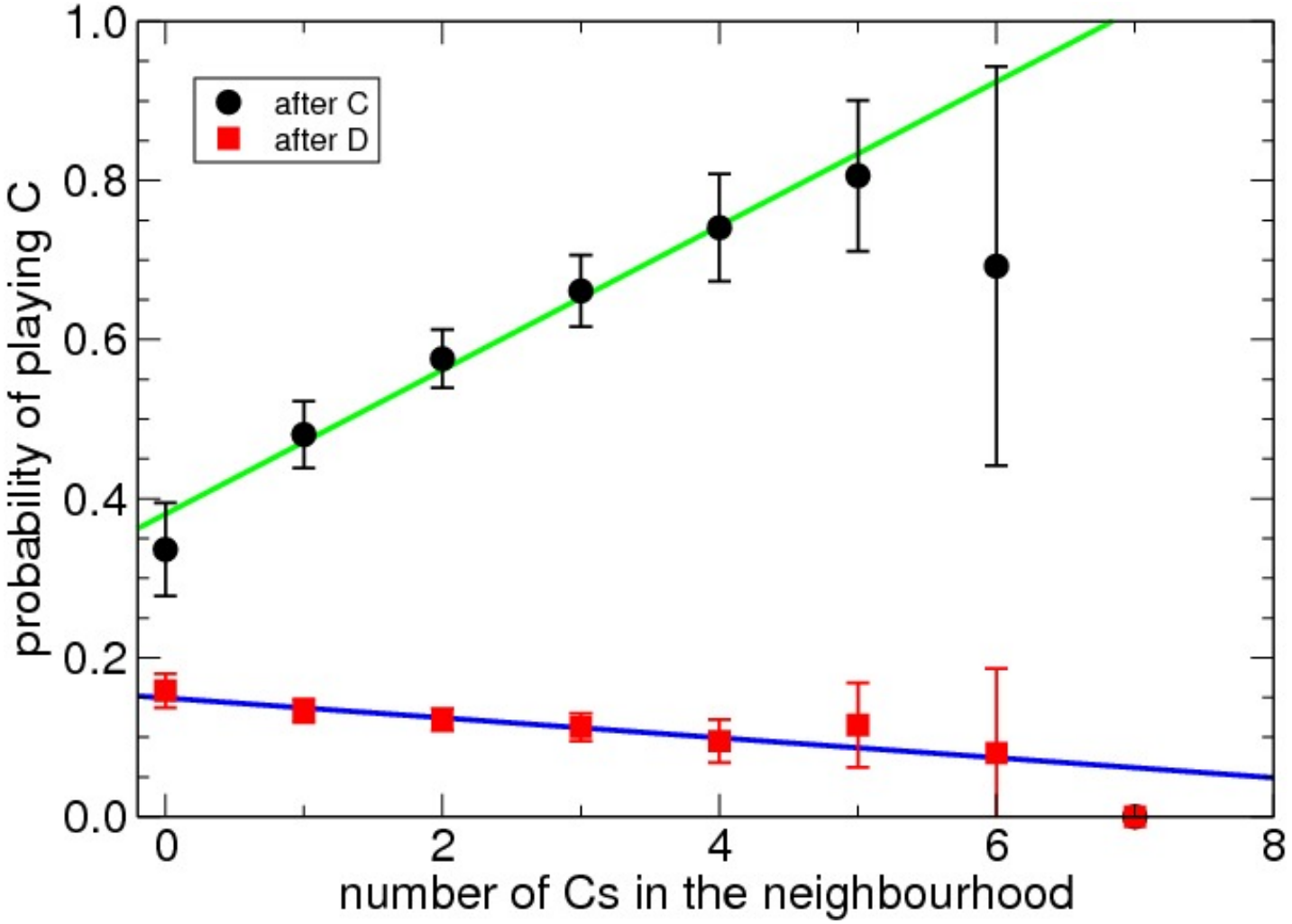
experimental = 0.7687
random = 0.7678 ± 0.0013
p-test = 0.282

PROBABILITY OF COOPERATION EXP1

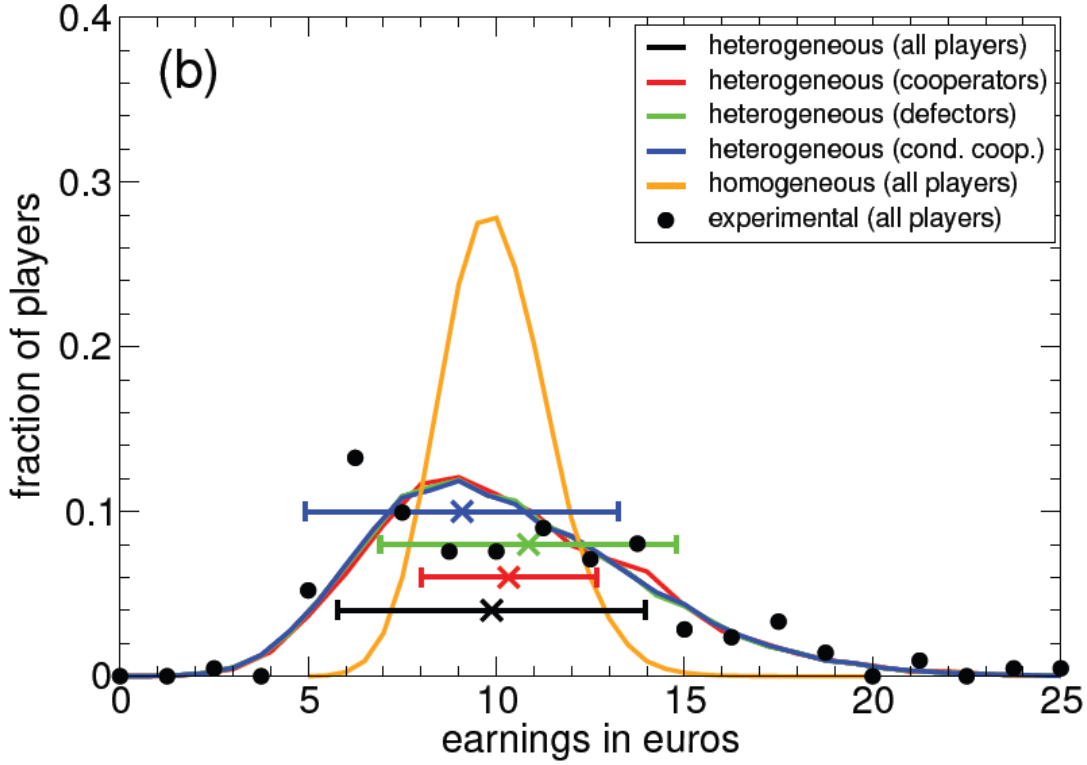


Conditional cooperation, introduced by Fischbacher, Gächter and Fehr (2001)

PROBABILITY OF COOPERATION EXP2



HETEROGENEITY



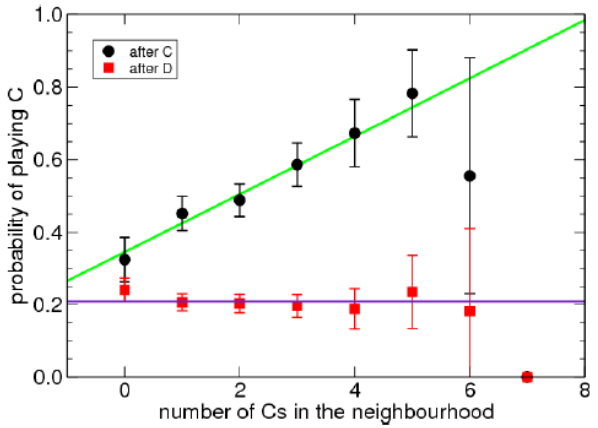
Type of player	Mark	Experiment 1	Control	Experiment 2
Defectors	**D**	24%	43%	41%
Cooperators	**C**	1.8%	1.8%	5.3%
Conditional cooperators	**X**	74%	56%	54%

MODEL

- Low, non zero cooperation
- No unconditional imitation
- Moody conditional cooperators
- Why this heterogeneity?
- Is there an evolutionary explanation?
- For analytics, we start with the simplest case:
  - pairwise prisoner's dilemma
  - Groups of 3, 4, 5
- Replicator dynamics
- Markov chain

J. Grujić, JA. Cuesta, A. Sánchez, J. Theor. Biol. **300**, 299-308 (2012)

REPLICATOR DYNAMICS



Player's action in the previous round	C	C	D	D
Opponent's action in the previous round	C	D	C	D
Type 1: mostly defectors	$1-p$	$1-p$	$1-p$	$1-p$
Type 2: mostly cooperators	p	p	p	p
Type 3: conditional cooperators	p_{C1}	p_{C0}	p_D	p_D

- Replicator equation:

$$\dot{x}_i = x_i \left[(\mathbf{A}\vec{x})_i - \vec{x}\mathbf{A}\vec{x} \right]$$

- What are the frequencies?

PAYOFF MATRIX

- Payoff, expected gain A_{ij}
- How to calculate **A**?
- Pure cooperators and pure defectors (p=1)

$$A = \begin{bmatrix} P & T & x \\ S & R & x \\ x & x & x \end{bmatrix}$$

- If $p < 1$ what is A_{11}

$$(1-p)(1-p)R + (1-p)pS + p(1-p)T + ppP$$

- For A_{13} we need transition probability matrix

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TRANSITION PROBABILITY MATRIX

	C C	C D	D C	D D
C C	M_{11}	M_{12}	M_{13}	M_{14}
C D	M_{21}	M_{22}	M_{23}	M_{24}
D C	M_{31}	M_{32}	M_{33}	M_{34}
D D	M_{41}	M_{42}	M_{43}	M_{44}

- Transition probability matrix of a Markov chain
- M_{31} is probability that if focal player played D and his opponent played C, they will both play C in the next round

TRANSITION PROBABILITY MATRIX

Matrix for D–X interaction:

$$M(1-3) = \begin{pmatrix} (1-p)p_{C1} & (1-p)(1-p_{C1}) & pp_{C1} & p(1-p_{C1}) \\ (1-p)p_{D} & (1-p)(1-p_{D}) & pp_{D} & p(1-p_{D}) \\ (1-p)p_{C0} & (1-p)(1-p_{C0}) & pp_{C0} & p(1-p_{C0}) \\ (1-p)p_{D} & (1-p)(1-p_{D}) & pp_{D} & p(1-p_{D}) \end{pmatrix}$$

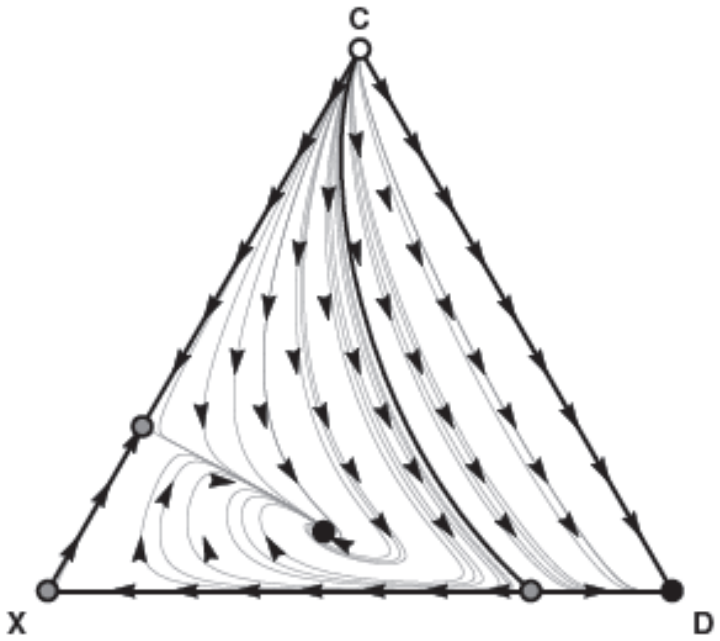
- Stationary probability vector

$$\pi = \pi \mathbf{M}$$

$$\pi = (\pi_{CC}, \pi_{CD}, \pi_{DC}, \pi_{DD})$$

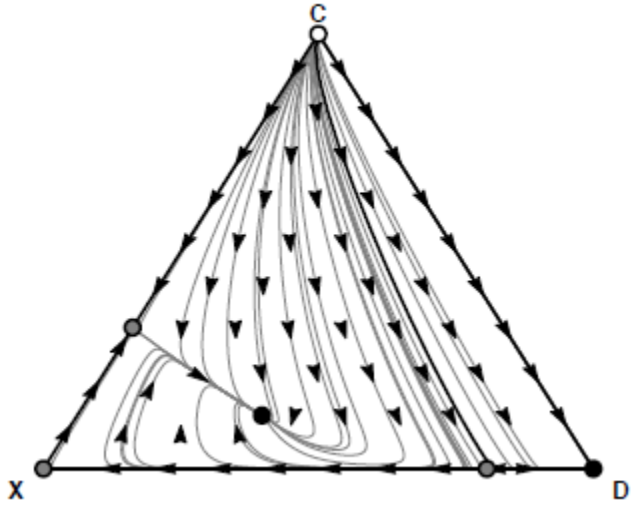
$$A_{ij} = R\pi_{\mathrm{CC}} + S\pi_{\mathrm{CD}} + T\pi_{\mathrm{DC}} + P\pi_{\mathrm{DD}}$$

DYNAMICS IN PAIRWISE PRISONER'S DILEMMA

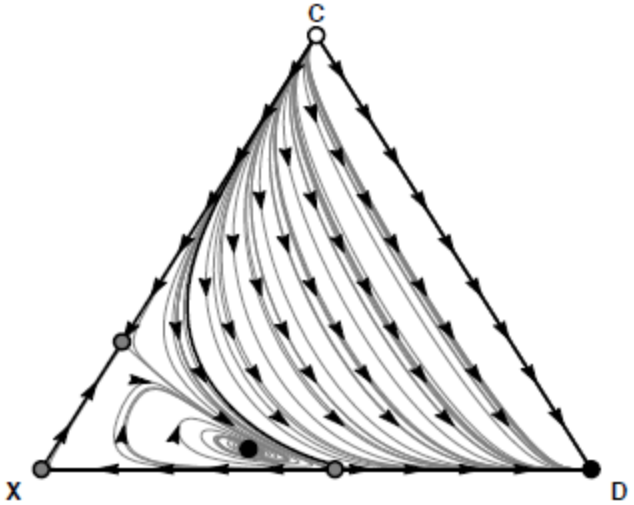


	Defectors	Cooperators	Conditional cooperators
Model	0.39	0.11	0.50
Experiment 1	0.24	0.018	0.74
Experiment 2	0.41	0.053	0.54

MULTIPLAYER'S PRISONER'S DILEMMA



3 players



4 players

For 5 players is hard to find an interior attractor

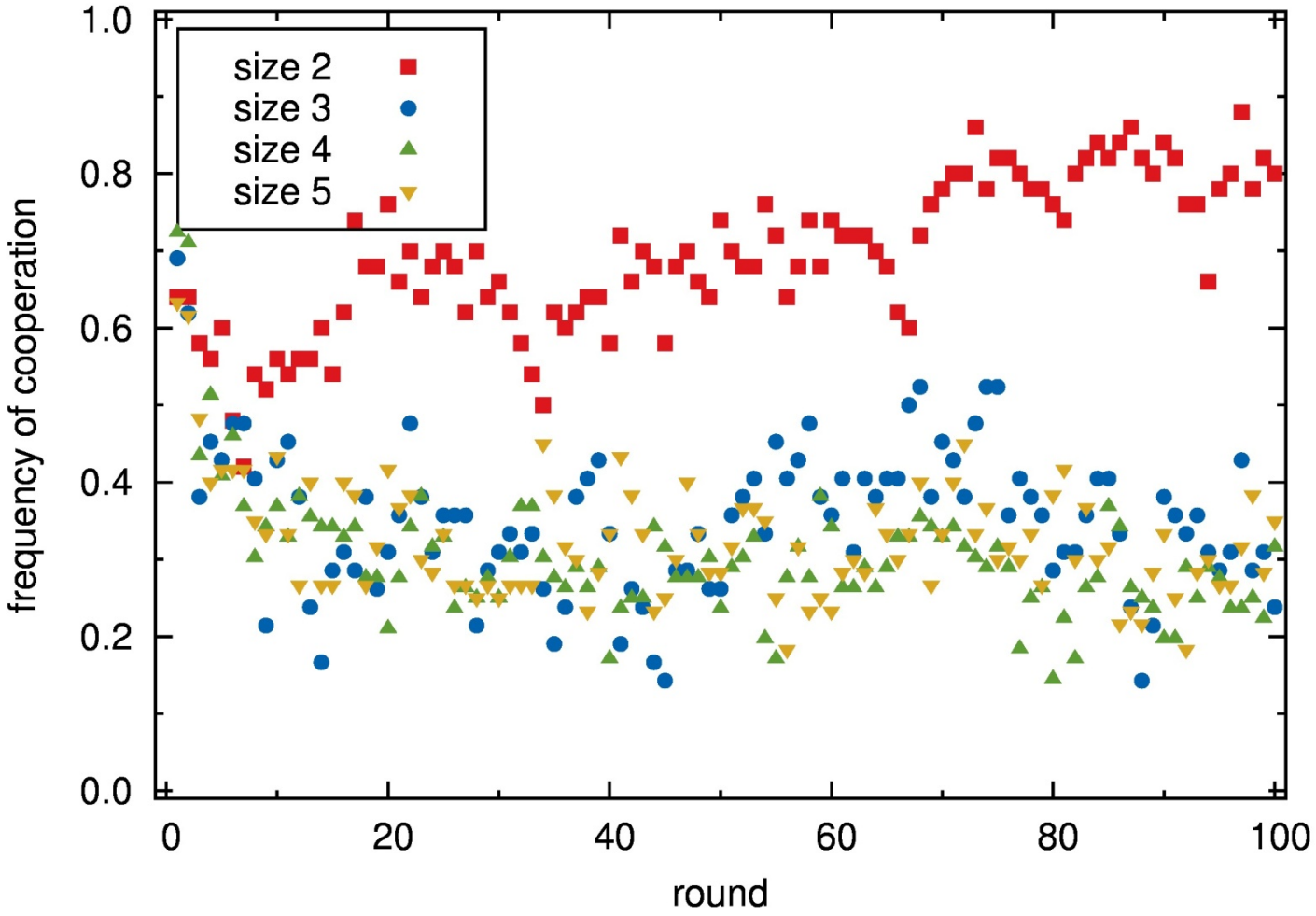
$n \to \infty$, no interior attractor

GROUPS EXPERIMENT

- Off lattice
- Iterated Multi-Players (2, 3, 4, 5) Prisoner's Dilemma
- 228 subjects in total
- Software in Z-Tree
- Payoffs to obtain similar earnings in all sizes
- 45 min sessions, at 10h, 12h, 14h, 16h, 3 days

J.Grujić, B. Eke, A. Cabrales, JA. Cuesta, A. Sánchez , Sci. Rep. **2**, 638 (2012)

COOPERATION LEVEL



OTHER EXPERIMENTS

R. Kümmerli et al. Proc. R. Soc. B, (2007)

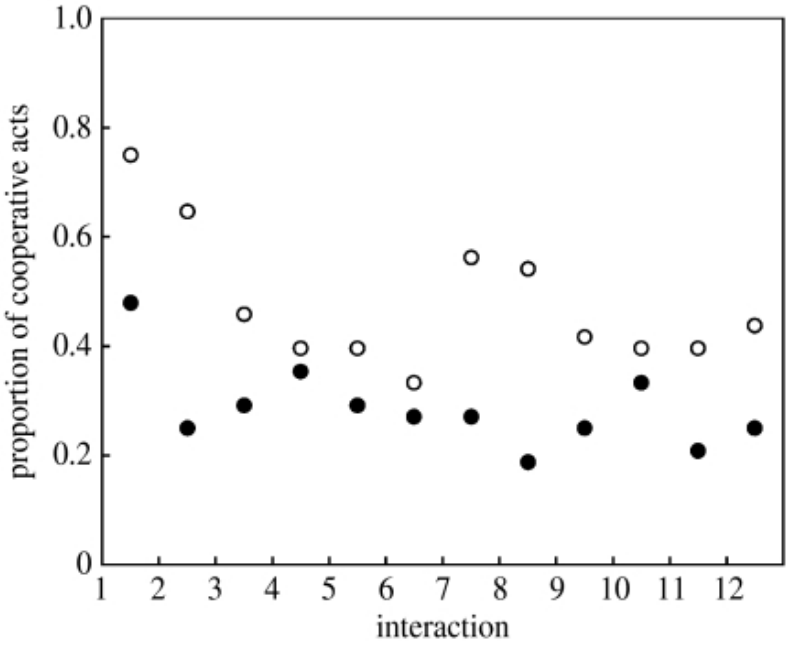
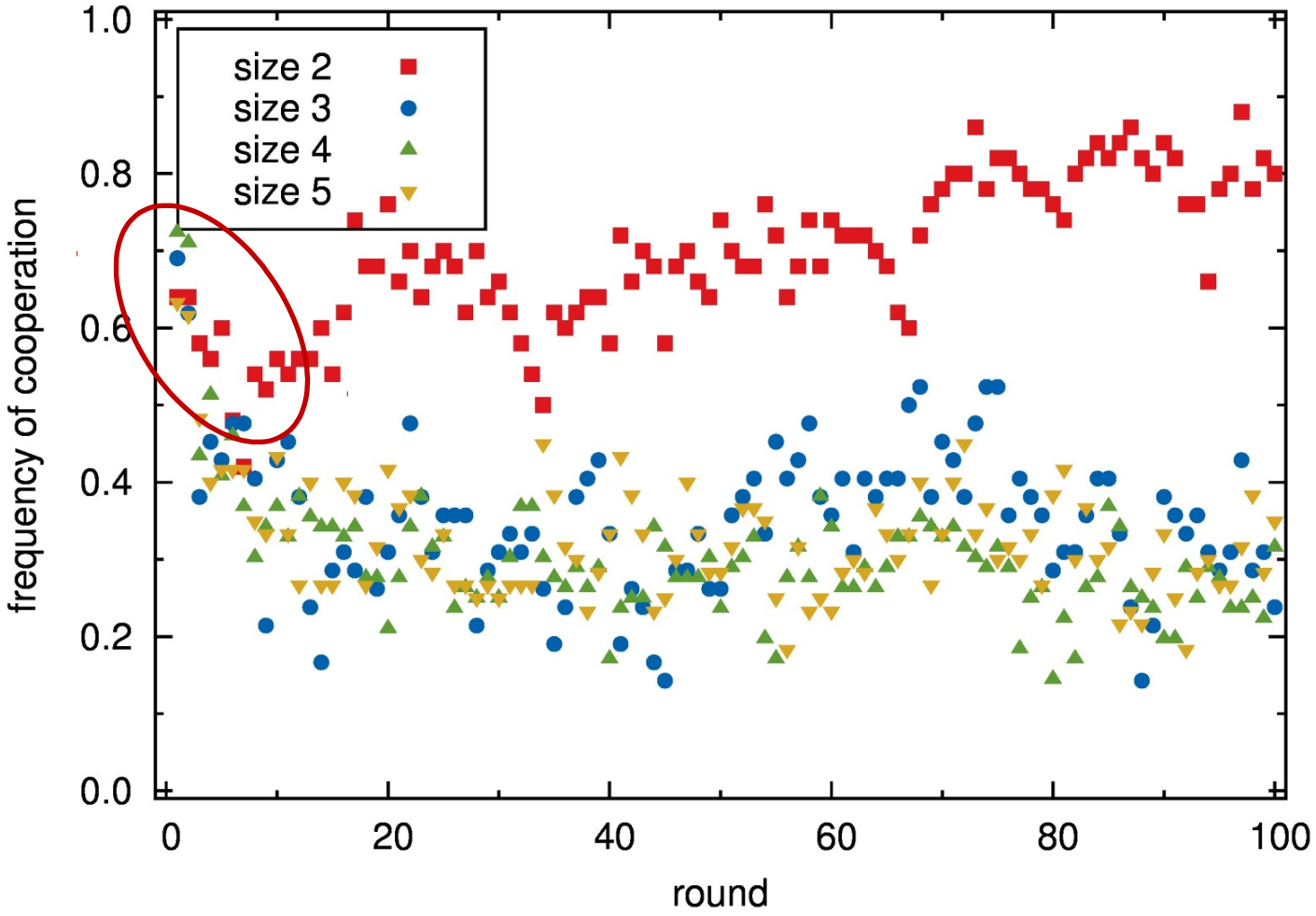


TABLE 6—PERCENTAGE OF COOPERATION BY ROUND AND TREATMENT*

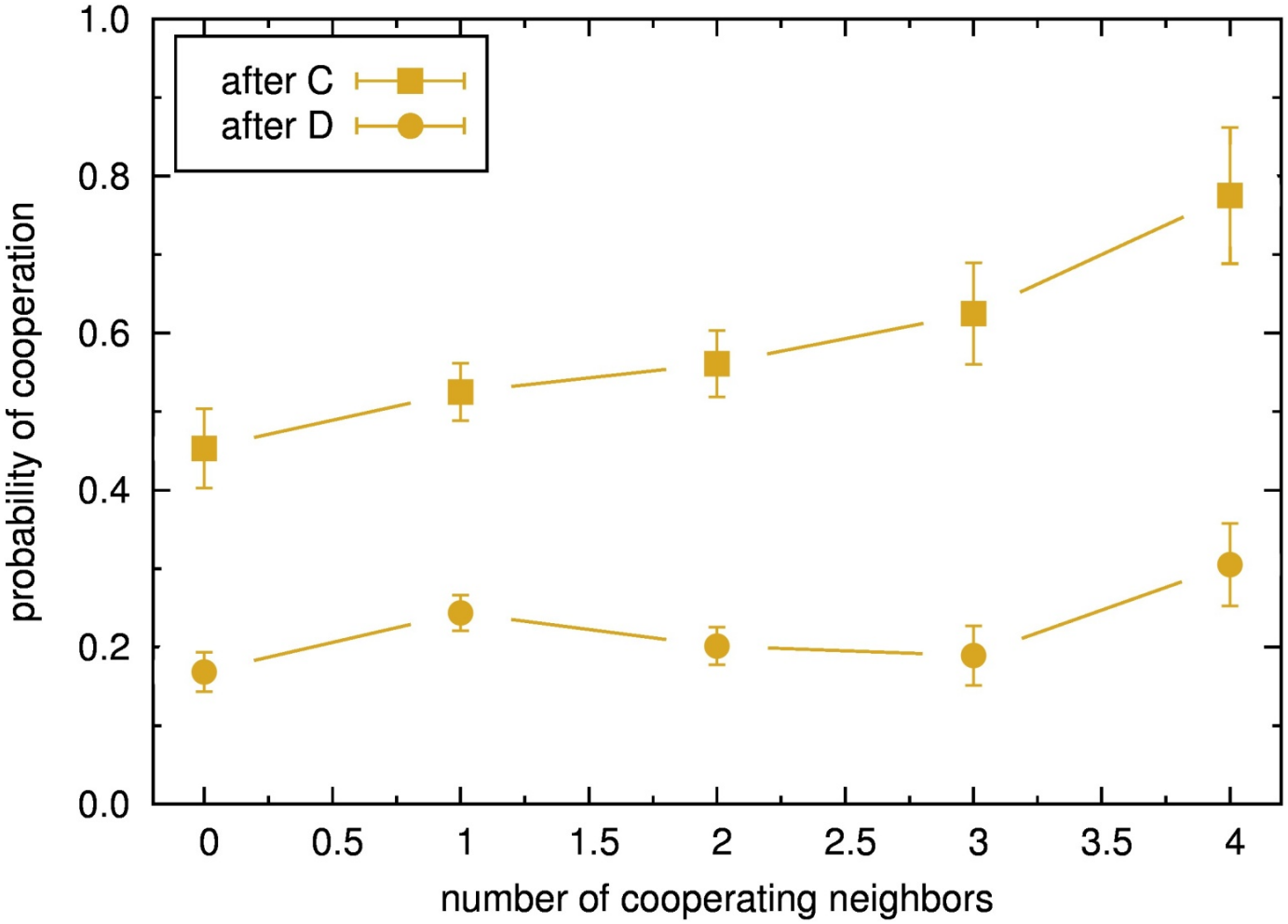
		Round											
		1	2	3	4	5	6	7	8	9	10	11	12
Dice	$\delta = 0$	9.17											
	$\delta = ½$	30.93	26.10	19.87	12.50	12.96							
	$\delta = ¾$	46.20	40.76	38.76	34.58	33.04	27.27	24.75	26.28	29.17	26.04	32.29	31.25
Finite	$H = 1$	10.34											
	$H = 2$	13.31	6.90										
	$H = 4$	34.58	21.55	18.97	10.63								

P. Dal Bó, Am. Econ. Rev. (2005).

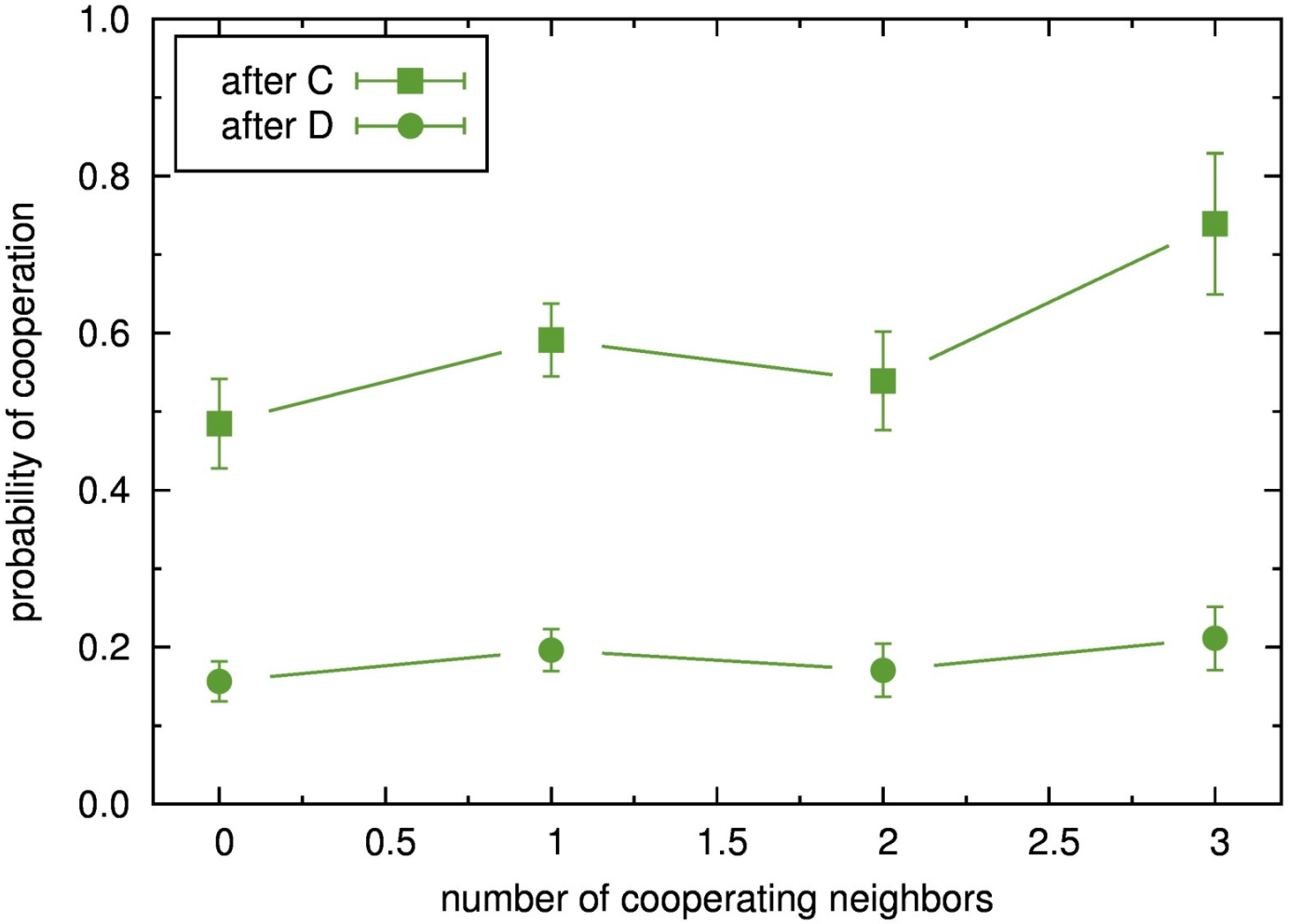
COOPERATION LEVEL



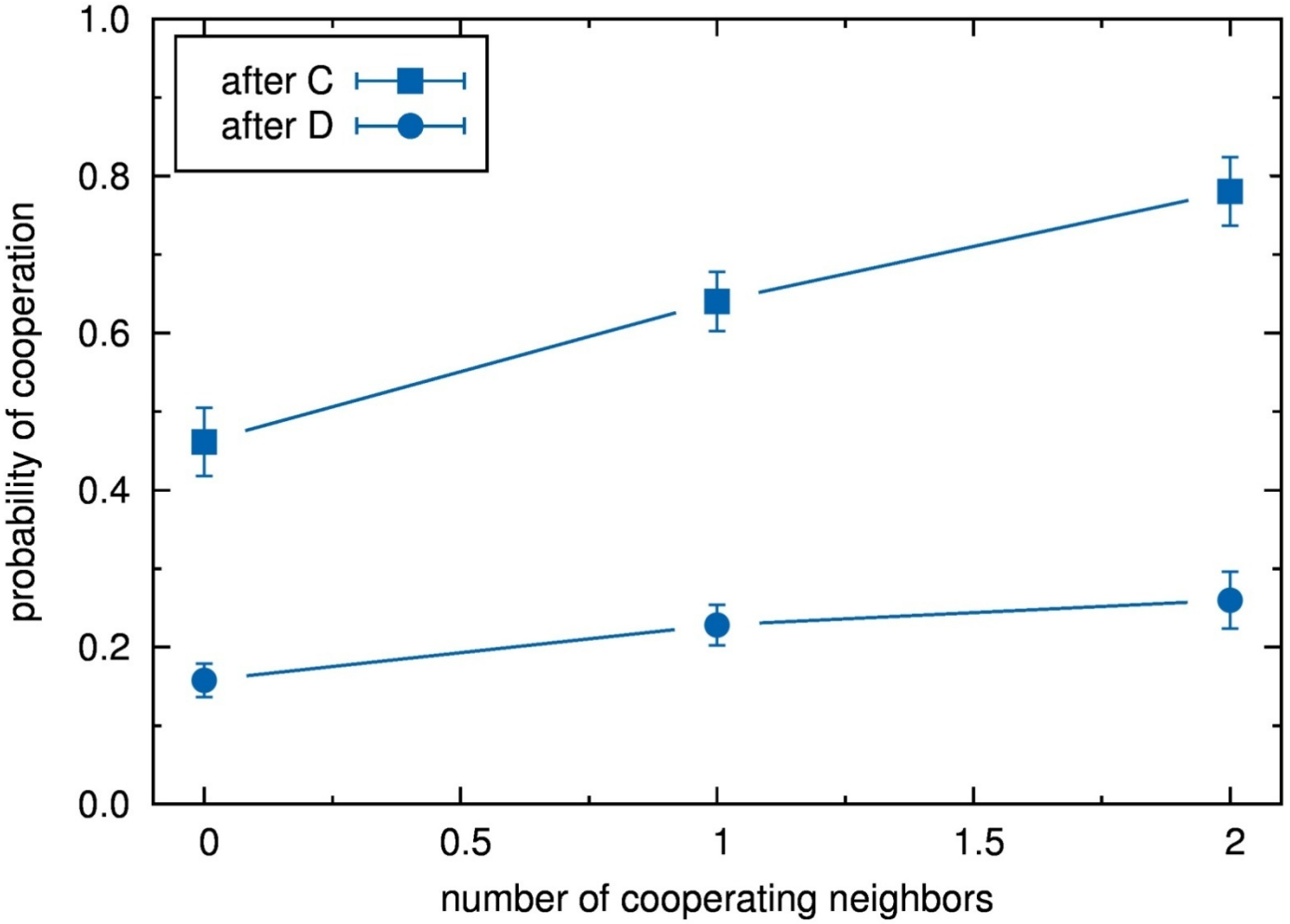
MOODY CONDITIONAL COOPERATORS – SIZE 5



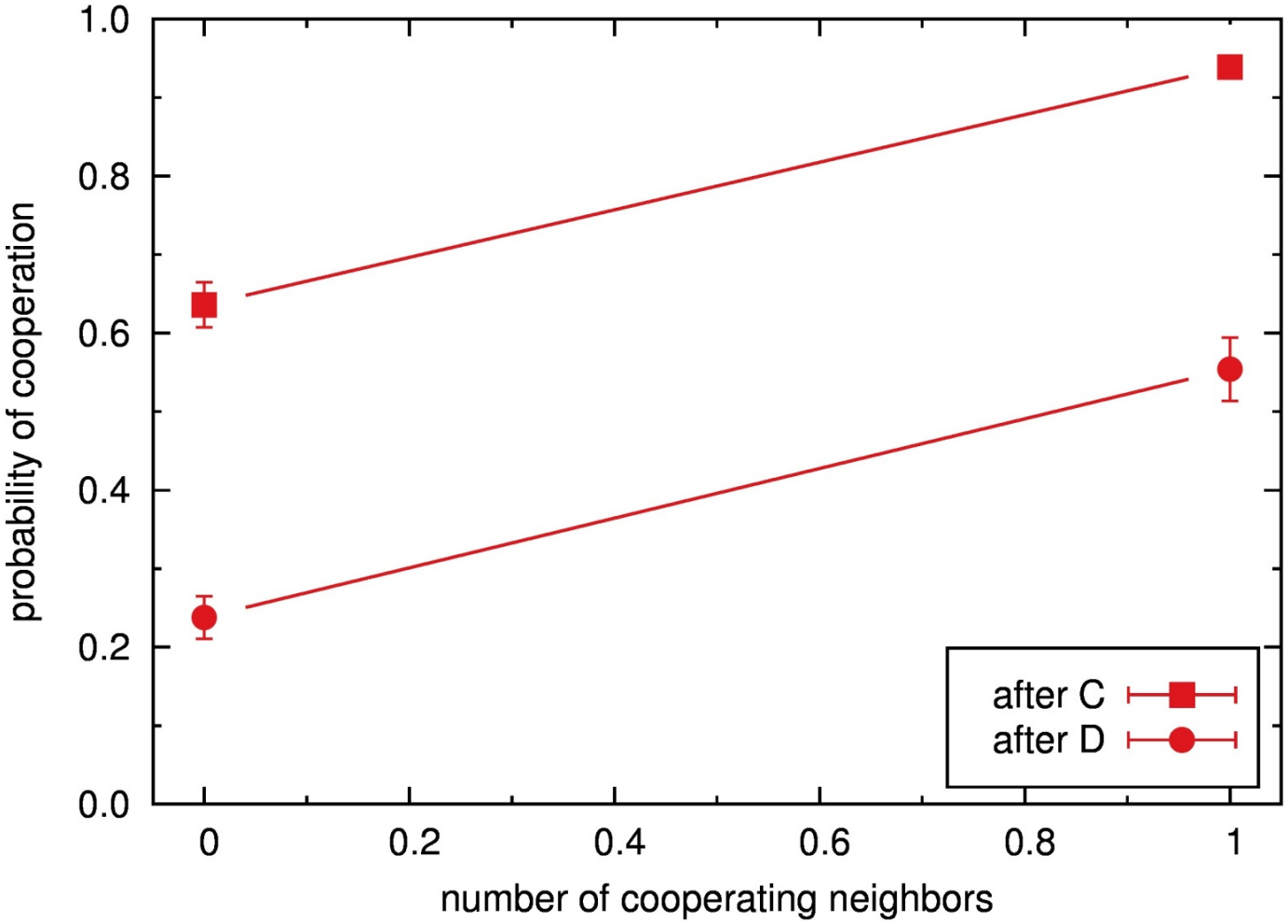
MOODY CONDITIONAL COOPERATORS – SIZE 4



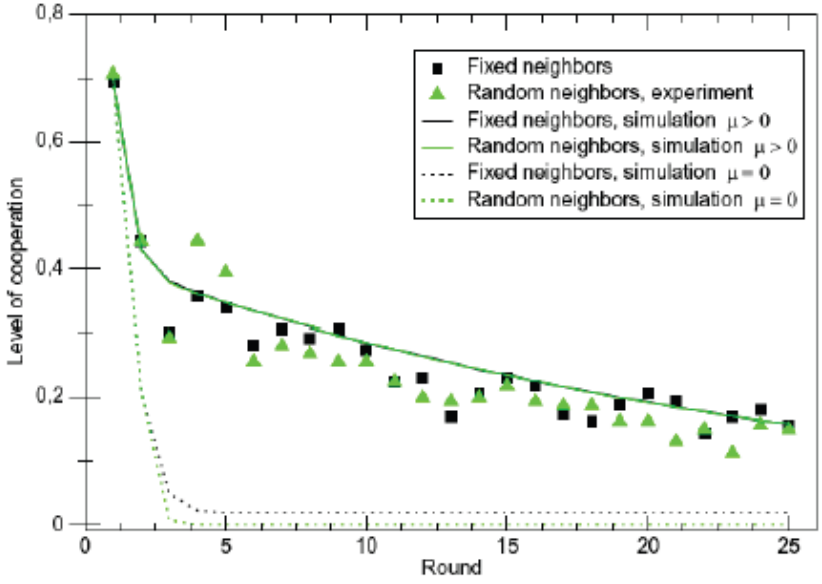
MOODY CONDITIONAL COOPERATORS – SIZE 3

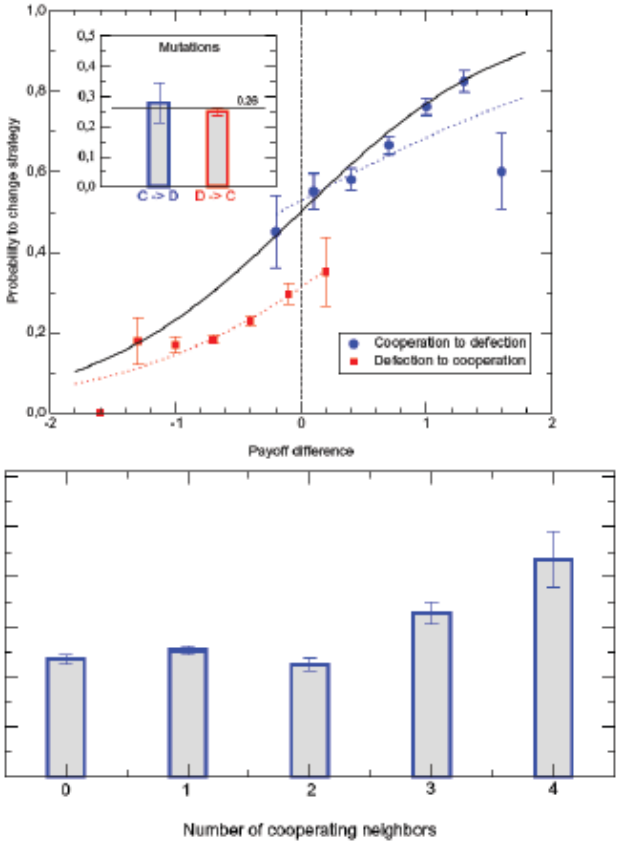


MOODY CONDITIONAL COOPERATORS – SIZE 2



PLÖN EXPERIMENT

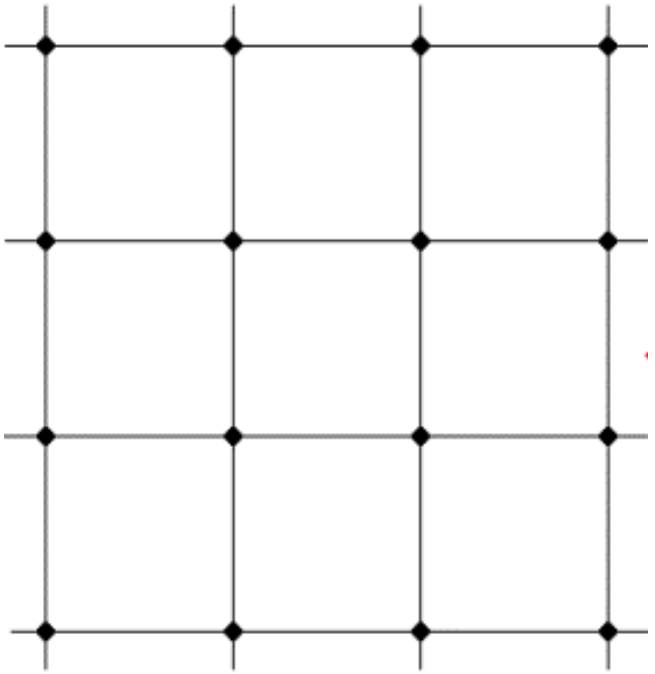





Going to Plön…

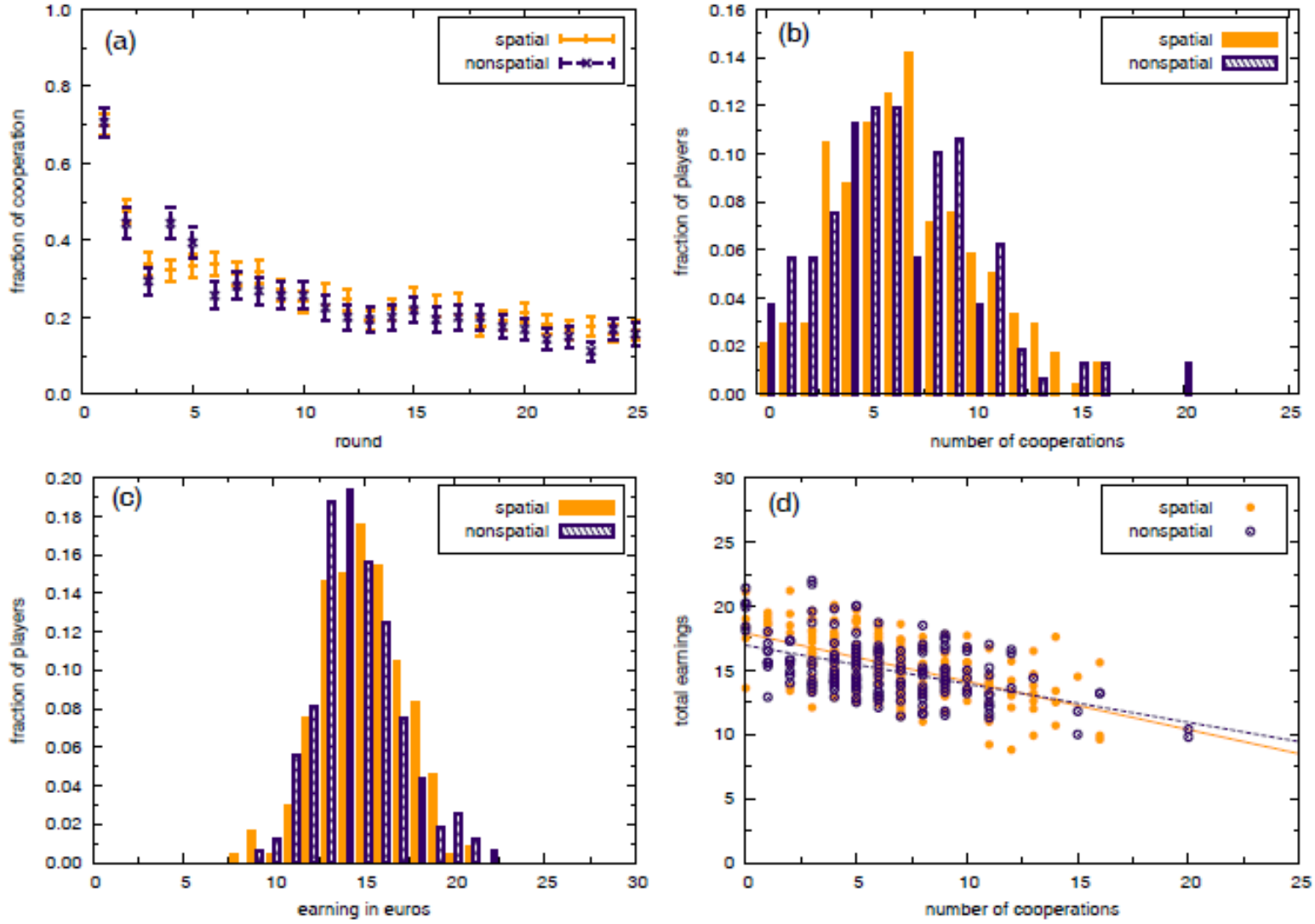
REANALYSIS OF THE DATA OF PLÖN EXPERIMENT

- Traulsen et al. PNAS (2010)
- 4×4 square lattice
- Multiple sessions
- Fully independent control
- True Prisoner’s Dilemma

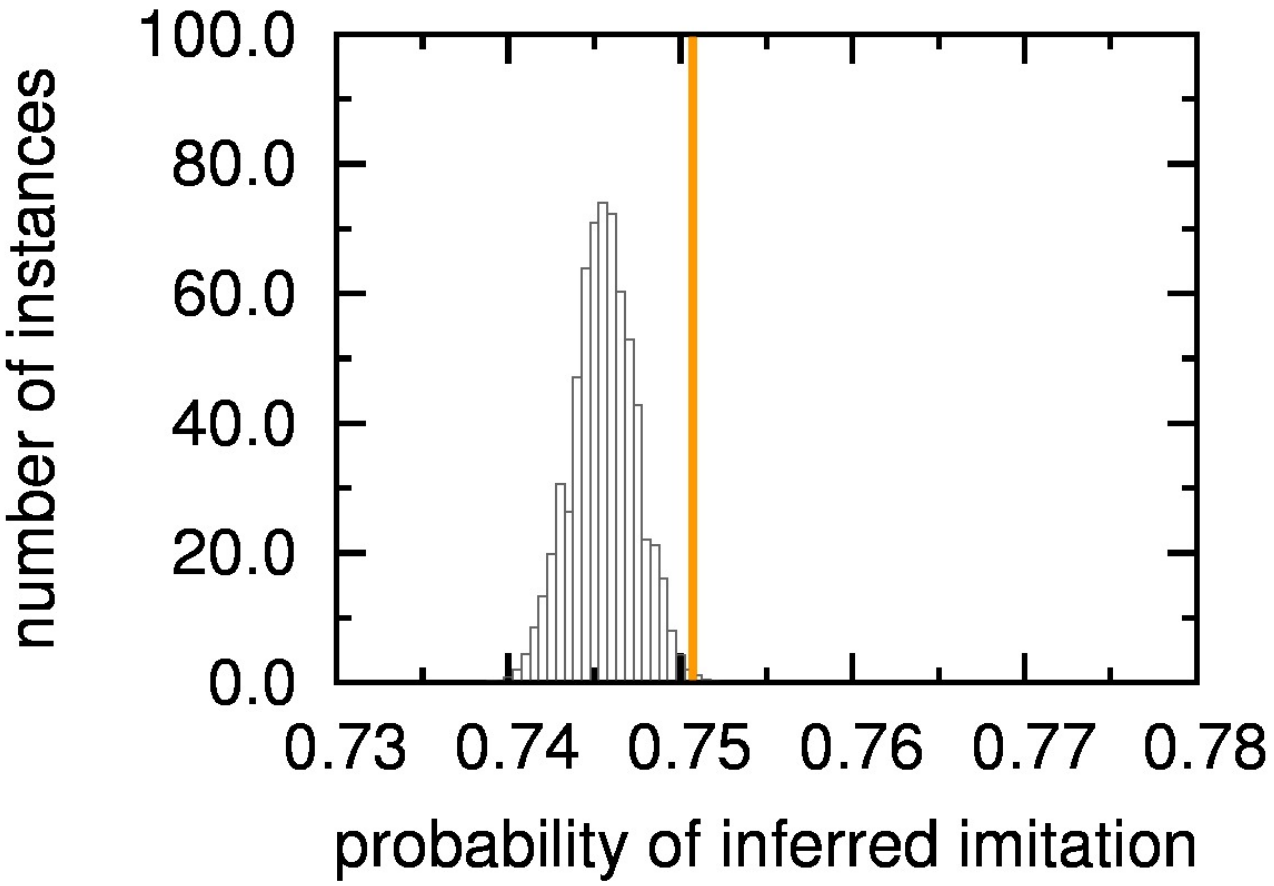


J.Grujić, T. Röhl, D. Semmann, M. Milinski, A. Traulsen, PLoS ONE, in press (201

EXPERIMENT - CONTROL

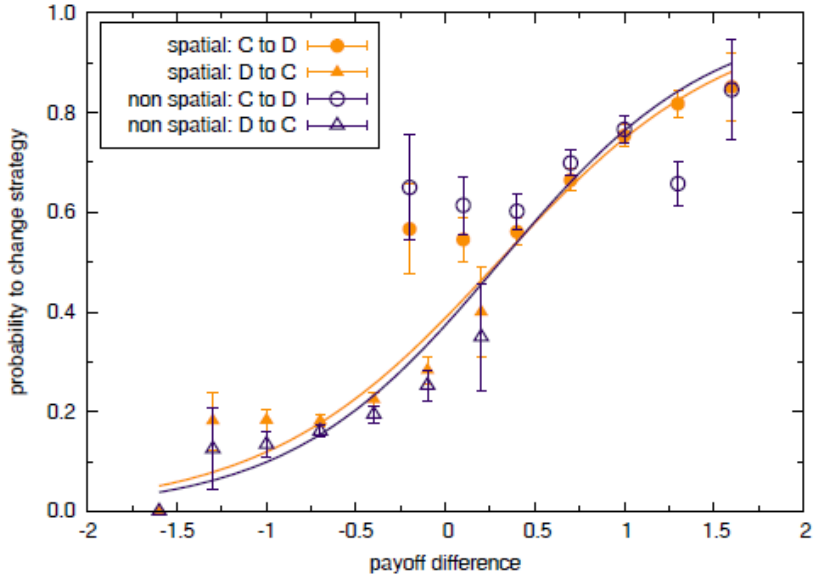


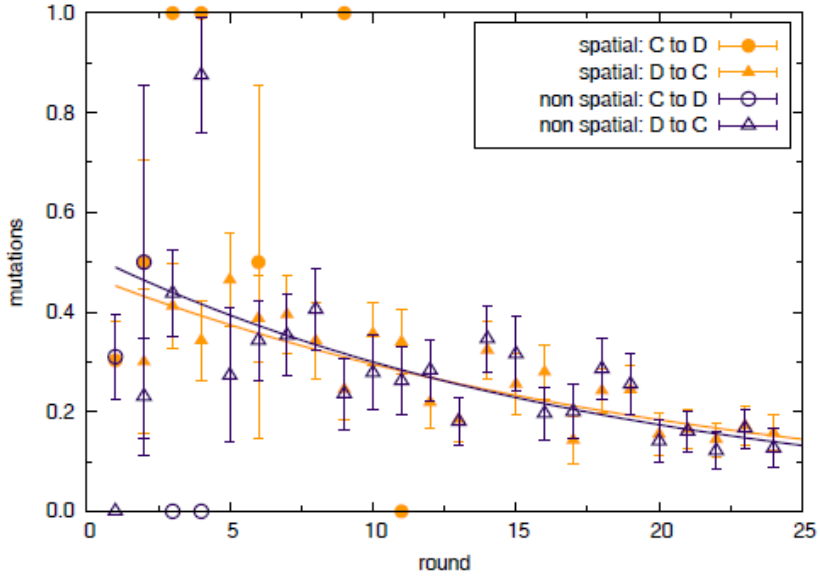
UNCONDITIONAL IMITATION



$$P_{A\to B}(\Delta\pi) = \mu\Gamma^{t-1} + (1 - 2\mu\Gamma^{t-1})\Theta(\Delta\pi)$$

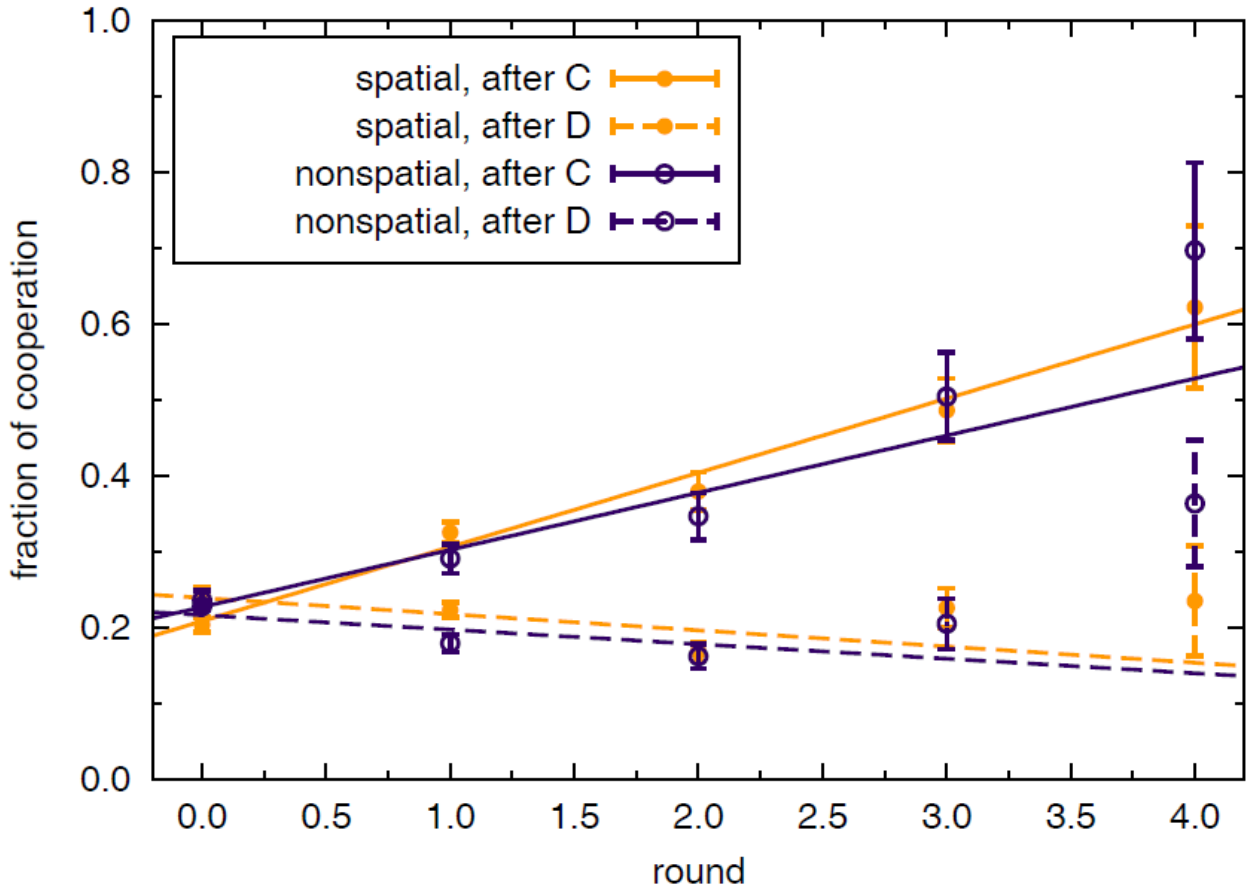
FERMI RULE





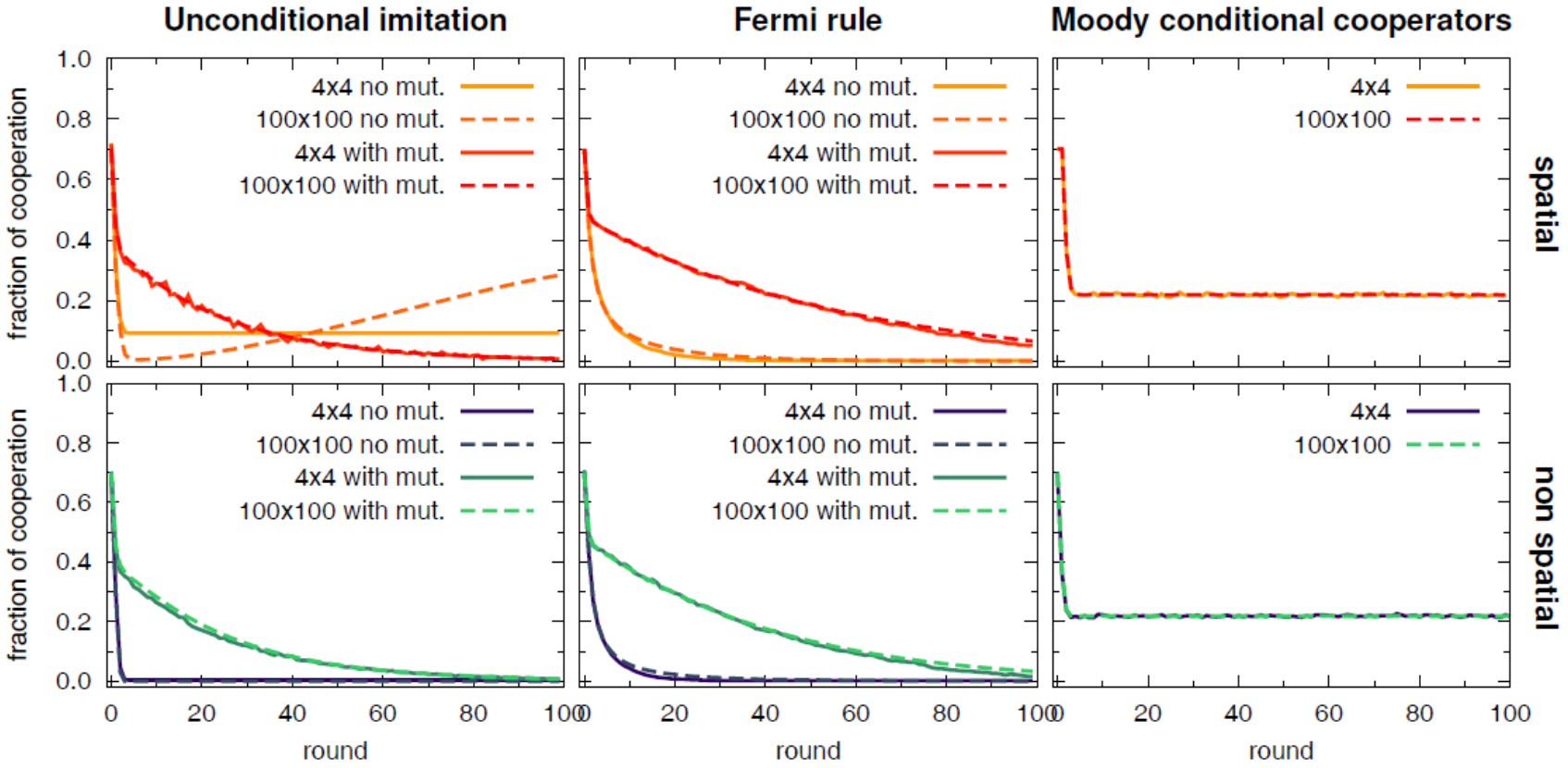
$$P_{C\leftrightarrow D}(\Delta\pi) = \mu\Gamma^{t-1} + (1 - 2\mu\Gamma^{t-1})\frac{1}{1 + e^{-\beta\Delta\pi+\alpha}}$$

MOODY CONDITIONAL COOPERATORS

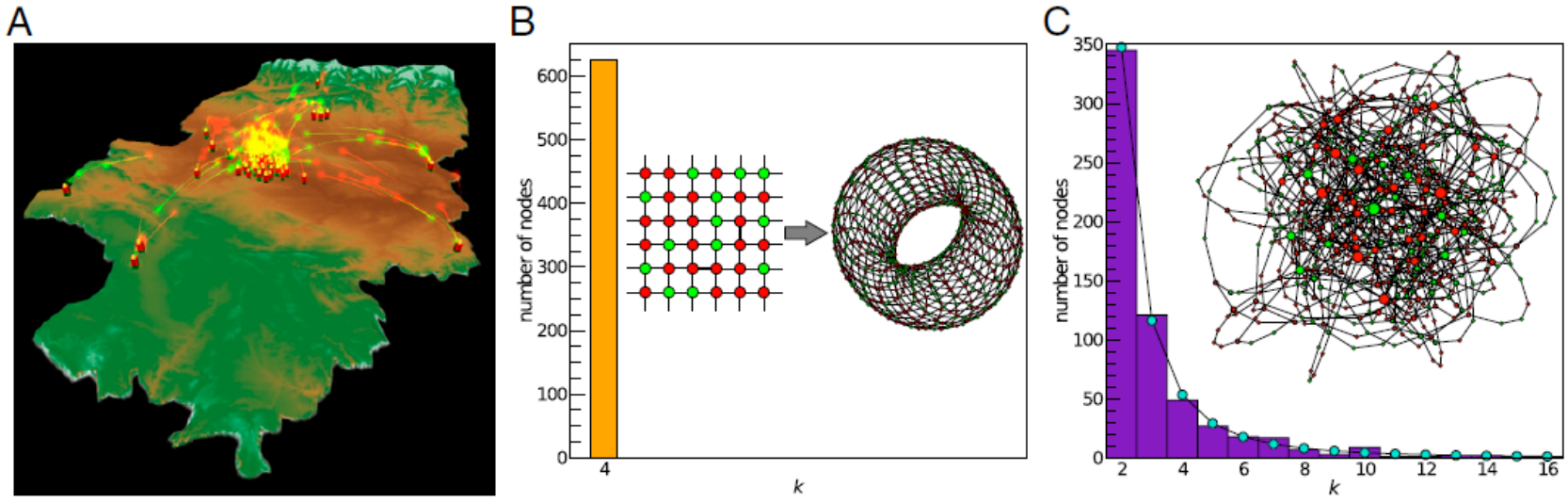


$$P_{C|C}(l) = a_C + b_C l \qquad P_{C|D}(l) = a_D + b_D l$$

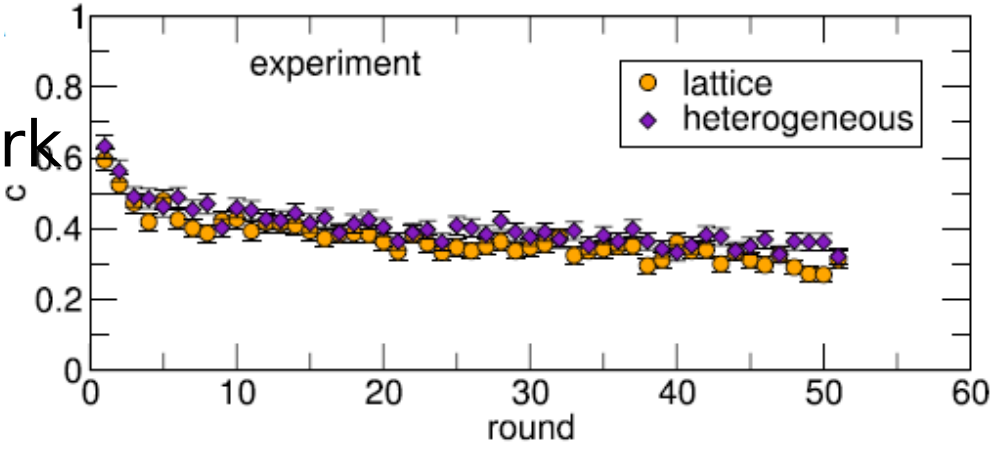
SIMULATIONS



ZARAGOZA EXPERIMENT



- Gracia-Lázaro et al., PNAS (2012)
- Lattice 25×25 nodes
- Heterogenous network

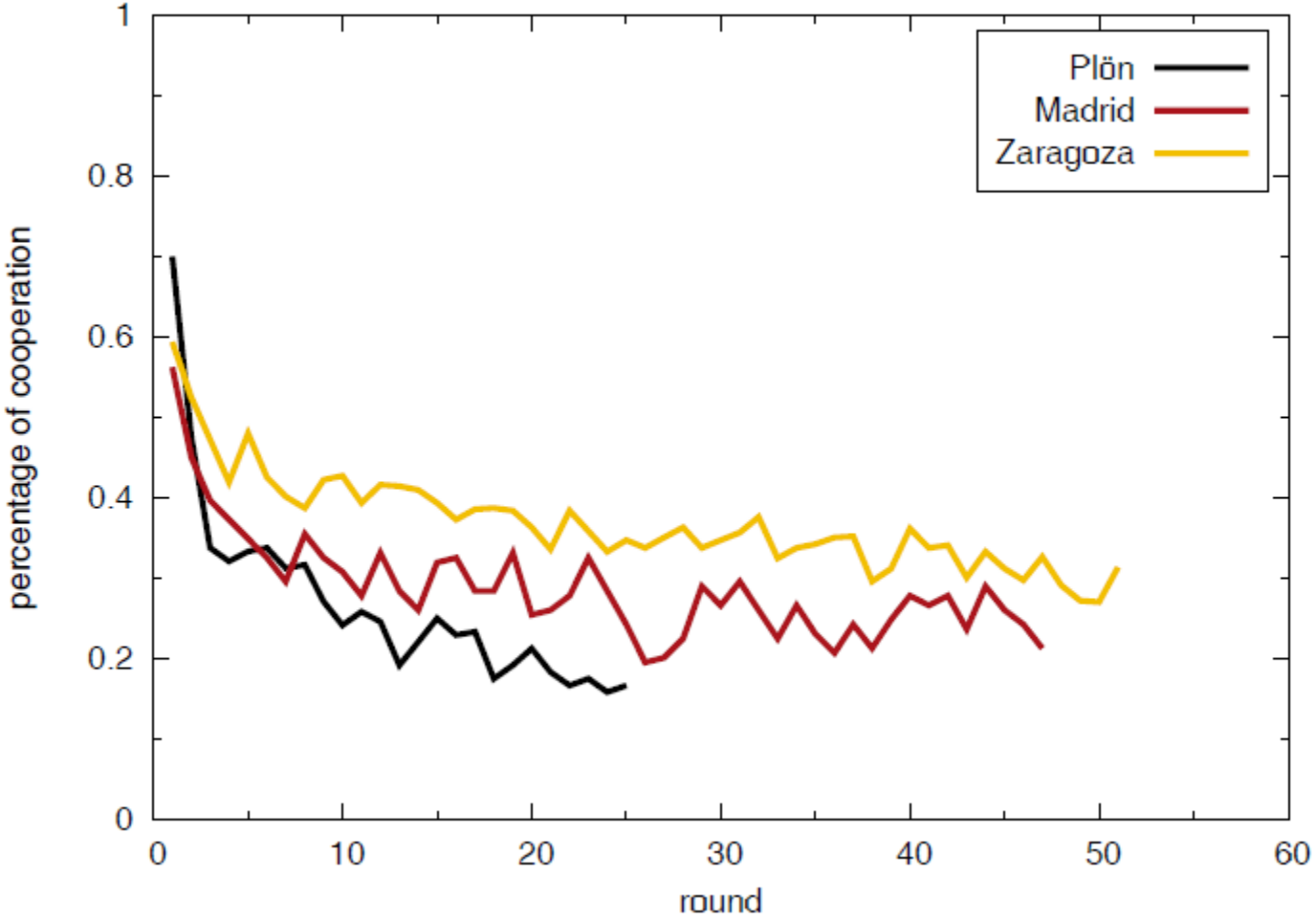


COMPARISON OF THE EXPERIMENTS

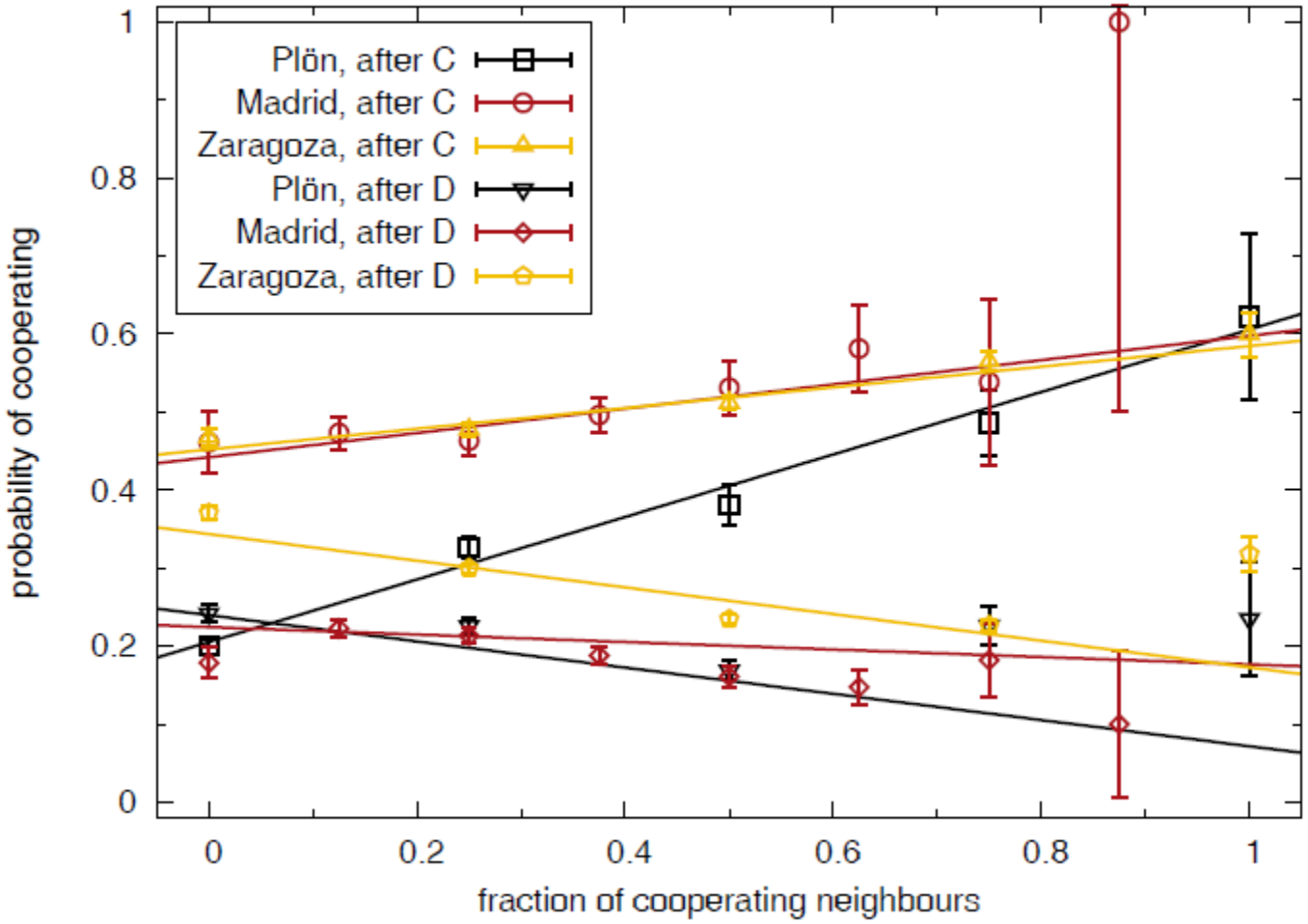
	Plön	Madrid	Zaragoza
Size of the network	4×4	13×13	25×25
Neighborhood	von Neumann's	Moore's	von Neumann's
Number of rounds	25	47	52
Number of sessions	15	1	1
Payoff matrix	C: 3, 0 / D: 4, 1	C: 7, 0 / D: 10, 0	C: 7, 0 / D: 10, 0
# of different players	240	169	625
# of actions	6000	7943	32500

Table 6.1: Comparison of the experimental settings for the three experiments on lattices. A von Neumann's neighborhood consists of the four nearest neighbors in a square lattice, whereas a Moore's neighborhood comprises all eight surrounding neighbors in the same lattice.

COMPARISON OF THE EXPERIMENTS



COMPARISON OF THE EXPERIMENTS



CONCLUSIONS

- Experiments on spatial prisoner’s dilemma
- Low but non zero cooperation level
- High cooperation level only in pairwise iterated case
- Unconditional imitation only with mutations
- In all cases moody conditional cooperators
- In Plön experiment spatial and non spatial not significantly different
- Spatial structure did not promote cooperation in any experiment
- People use strategies which do not promote cooperation in spatial structure

dank u
merci
danke
obrigado
arigatô
tänan
gràcies
gracias
thank you
grazie
dankie
hvala
shukran
kiitos
хвала
tak
takk
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благодаря
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děkuji
mahalo
terima kasih
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grazzi
mh'gōi
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