Cooperation and Conflict in the Prisoner’s Dilemma and the Emergence of Norms

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with Wenjian Yu, Carlos Roca, Sergi Lozano,
Anders Johansson, Heiko Rauhut and others
Emergence of Coordination in Pedestrian Counterflows

Based on individual interactions, lanes of uniform walking directions emerge in pedestrian crowds by self-organization. This constitutes a "macroscopic" social structure. Nobody orchestrates this collective behavior, and most people are not even aware of it. A behavioral convention "institutionalizes" a side preference.

Acts like Adam Smith’s “invisible hand”
Breakdown of Coordination: Stop-and-Go and Turbulence Flow

The density times the variation in speeds constitutes the hazard! Pressure fluctuations cause turbulent motion and potentially the falling and trampling of people.

Increased driving forces occur in crowded areas when trying to gain space, particularly during “crowd panic”
The Miracle of Cooperation and Social Norms

- **Without cooperation**, our **social benefit systems** would not work, our environment would be overly exploited and polluted, and we would be victims of the “tragedy of the commons”, the public goods dilemma, i.e. society would be on a primitive level.

- **Social dilemmas** are mathematically described by the public goods game, the prisoner’s dilemma, the snowdrift, stag hunt, and other games.

- **Norms** represent shared behavioral rules and constitute a major part of our **culture**. They have been called the **cement** (J. Elster) or **grammar** of society (C. Bicchieri). In fact, they guide our behavior like an **invisible hand** (A. Smith), thereby giving social interactions a certain **structure** (“scaffolding”), and they support efficient interactions, thereby acting like a “**lubricant**”.

- While the **evolution of conventions** is described by coordination games, the evolution of norms seems to require a **sanctioning** (“punishment”) of non-conforming behavior.

- Still, the evolution of cooperation and norms is **not fully understood**. For example, **how are the two related?** Is it the same problem or not?
Evolutionary Games: Self-Organization of A Behavioral Convention

The result of a social interaction between two individuals is characterized by the “payoff”

If $p(1,t)$ denotes the probability of pedestrians to evade on the right and $p(2,t)$ to the left, the expected payoff (“success”) is $S(i,t) = Bp(i,t)$, when using strategy $i$. The average success of pedestrians is $A(t) = p(1,t)Bp(1,t) + p(2,t)Bp(2,t)$, where $p(2,t) = 1 - p(1,t)$. Due to strategy changes (success-driven imitation), the proportion of strategy $i$ grows proportionally to the difference between the expected success and the average expected success: $dp(i,t)/dt = r[S(i,t) - A(t)]p(i,t)$

$$dp(i,t)/dt = -2rB[p(i,t)-1/2]p(i,t) [1-p(i,t)]$$

$i=1$: right, $i=2$: left

Only the stationary solutions $P(i,t)=0$ or $1$ are stable, i.e. one evading side will become a behavioral convention (Helbing, 1990, 1991, 1992)
The Prisoner’s Dilemma (PD)

In the prisoner’s dilemma, the same analysis leads to defection only.

The prisoner's dilemma game has served as prime example of strategic conflict among individuals. It assumes that, when two individuals cooperate, both get the “reward” $R$, while both receive the “punishment” $P < R$, if they defect. If one of them cooperates (“C”) and the other one defects (“D”), the cooperator suffers the “sucker’s payoff” $S < P$, while the payoff $T > R$ for the second individual reflects the “temptation” to defect. Additionally, one typically assumes $S + T < 2R$.

Many “social dilemmas” are of a similar kind (e.g. the public goods game)
Overview of Mechanisms Supporting Cooperation

Mechanisms:
1. Genetic relatedness
2. Repeated interaction
3. Reputation
4. Clustering
5. Competition also between groups

Routes to cooperation require to **destabilize defection** (PD --> SD) or to **stabilize cooperation** (PD --> SH) or both (PD --> HG)

**PD** = Prisoner’s Dilemma
**HG** = Harmony Game
**SH** = Stag Hunt Game
**SD** = Snowdrift Game

**Route 1:** Kin+group selection, network reciprocity, 2a: Direct reciprocity, 2b: Indirect reciprocity, 2c: Costly punishment, 3, 4: Kin selection, 5: Network interactions
Routes to Cooperation when Manipulating Payoffs

Route 1: From PD to HG
Route 2: From PD to SH
Route 3: From PD to HG via SD
Route 4: From PD to HG via SH

PD=Prisoner’s Dilemma, HG=Harmony Game, SH=Stag Hunt, SD=Snowdrift Game
Herding Effect in the Prisoner’s Dilemma “Inverts” the Outcome!

Assume that payoffs depend on the strategy distribution. Even a simple linear dependence changes system behavior dramatically!

Fraction of cooperators

Strength of Herding Effect

0

k

DEFECT

COEXIST

MULTISTAB

1

p
Conflict between Individuals Preferring Equity and Equality Norms

Results of an Ultimatum Game Experiment

Work with Fabian Winter and Heiko Rauhut (see separate talk)
Situation in Two Populations with Conflicting Interests

Only in the Stag Hunt Game we find that both populations tend to use the same behavioral strategy, i.e. a behavioral norm evolves! The norm-creating mechanism is also important for the evolution of language.
How to Transform the Prisoner’s Dilemma into Other Games

Route 1: Kin selection, 3: Network interactions (don’t support norms)
2a: Direct reciprocity, 2b: Indirect reciprocity, 2c: Punishment (support norms)
Marrying Models of Motion with Game Theory

- What will happen when integrating game-theoretical models and models of mobility?
- Will the resulting individual-based models produce new kinds of self-organization?
- Why are group, class, and niche formation, agglomeration, segregation etc. so widespread in social, economic, and biological systems, although one often tries do counteract these phenomena?
- What is the role of mobility for social cooperation?
- Is migration a “bad thing”?
- Does leaving the birth place necessarily reduce cooperation by cutting social ties, as one may think?
Nowak and May (1992) have extended the prisoner’s dilemma to simultaneous spatial interactions in an LxL grid involving L^2 players, assuming that each player would have binary interactions with m=8 nearest neighbors, and would afterwards imitate the strategy C or D of the most successful neighbor, if he or she performed better. Computer simulations for R=1 and P=S=0 show “chaotic” pattern formation phenomena in a certain parameter range of T.

For R=1 and P=S=0 Nowak and May have found that big clusters of defection shrink for T<1.8, while for T>2, cooperative clusters do not grow, and in between, both cooperative and defective clusters would expand, collide, and fragment.

We will now combine strategic interaction, as described by game theory, with a special, success-driven kind of motion. Individuals are assumed to have a preference for a favorable neighborhood. A higher expected payoff, i.e. a higher level of cooperation, makes a neighborhood more attractive.

We generalize the spatial prisoner’s dilemma by adding a success-driven motion step before the interaction and imitation steps. We assume that $N < L^2$ grid locations are occupied, and individuals can move to empty sites.

To keep things simple, for each empty site within a certain mobility radius $M$, each individual is assumed perform a “test interaction” to determine the fictitious total payoff that would result when moving to this location (“neighborhood exploration”). The individual would then move to the location with the highest payoff, and in case of several equivalent locations, to the closest of them. We assume a random sequential update and periodic boundary conditions.

Restricting migration to empty sites resembles relocations (e.g. between apartments) and reflects that individuals tend to occupy a certain territory.
Spatio-Temporal Pattern Formation Due to Success-Driven Migration

Segregation ("Lane Formation")

Repulsive Agglomeration ("Ghetto Formation")

Attractive Agglomeration ("Clustering")
Agglomeration in the Prisoner’s Dilemma and Snow Drift Game
Imitation and Success-Driven Motion, Separately and Together

\[
\begin{align*}
P &= 0 \\
R &= 1 \\
S &= 0 \\
T &= 1.4
\end{align*}
\]

imitation only

migration only

imitation & migration

blue = C
red = D
The Breakdown and Outbreak of Cooperation

Red, yellow: defectors (cheaters)
Blue, green: cooperators
Time-Dependence of Transition of Predominant Cooperation

Graph showing the fraction of cooperators over iterations for different parameter values. The graph includes a subplot indicating the total migratory distance of cooperators.
Route Choice Dilemma

M. Schreckenberg, R. Selten et al. (2001)
The 2-Person Route Choice Dilemma

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<th>Defection</th>
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<tr>
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a) The payoff matrix for the 2-person route choice dilemma.

b) Strategy matrix for route choice.

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The diagram illustrates the various game theory strategies and outcomes for the 2-person route choice dilemma.
Outbreak of Turn-Taking: Experiments and Simulations

2 Persons: Experiment

2 Persons: Simulation

Subsequent 4-Person Experiment

Multi-Period Decisions
Intermediate Summary

- Extending spatial games by success-driven migration allows to describe
  - survival and spreading of cooperation in large parameter area of the PD by spatio-temporal pattern formation
  - noise-resistance
  - outbreak of predominant cooperation

- Success-driven migration can destabilize a homogeneous strategy distribution, but produces adaptive, self-stabilizing patterns (rather than frozen ones), allowing cooperators to evade invasion attempts of defectors

- This “inverts” the result of the replicator equation predicting 100% defectors

- The mechanism is local, and it does not change the payoffs (in contrast to taxes or punishment, for example)

- Mobility is an important factor supporting human sociality
Ethnic areas and bomb attacks before 2006

Conflict occurs primarily at boundaries between areas with different ethnic fractions. Mixed areas shrink.

Source: BBC
Conflicts: Towards Simulating Conflicts

- Cultures refer to a set of symbols and meanings, including values and norms. They are regionally different.
- What may happen, if two populations with different, partially incompatible cultures start to mix (if we allow for migration)?
- Unilateral adaptation, mutual adaptation, conflict, segregation, or a combination of them?
If the player is dissatisfied (i.e. when satisfaction $s < 0$):

- migrate to a new position, in a range $-sR$, with a probability proportional to the number of available neighbors
- on a slower timescale, switch strategy with probability $-s$
Satisfaction Drives Migration and Strategy Choice
Emergence of Cooperation and Aggregation
Stabilization of Cooperative Strategies
How an Increase in Greediness Can Cause a Collapse of Cooperation
High Aspiration Level
Is the Result an Unstable and Disoriented Society?

What happens, when social bonds become weaker, but herding instinct remains?
Summary

A simple model considering strategy and location changes and noise can reproduce various *stylized facts* of social systems:

1. **Individuals like to agglomerate** (form cities, groups, etc.)
2. **Individuals with different behavioral strategies tend to segregate** (--> see also Schelling)
3. **Levels of cooperation** in the prisoner’s dilemma and in public goods games are *higher than expected*; they tend to break down, but may grow, if people can leave bad environments and choose more favorable ones
4. **Individual behaviors are partially determined by the social environment** they are contributing to (--> norms)
5. **Social environments persist** much longer than an average individual contributes to it (--> social institutions)
6. **Social systems perform well by continuous adaptation**
Thank you for your interest!

Any Questions?