



The Emergence of Cooperation with Stationary Leadership

Jens Hunhevicz, Jonas Stolle, Sophie Kerstan & Pietro Griffa

Agent-Based Modeling and Social System Simulation FS19

Introduction: Relevance of Studying Cooperation

Defection is tempting because it guarantees «the largest payoff regardless of what the others are doing». (Dercole et al., 2019)



In the real-world, however, people accumulate in social groups where cooperation is common...



...and even companies cooperate to boost their competitive advantage and flock together in certain areas.



Theoretical Background

Game theory as the underlying framework:
Prisoners Dilemma Game (PDG), Public Goods Game (PGG), ...

Mechanisms
protecting and partly
fostering cooperation
implemented in
models within the
literatur



Numerous
others

Project Goals & Outcome Expectations

Overarching Goal

To implement **different mechanisms** and their **combinations** into an agent-based model in order to investigate **what promotes cooperation** within the Prisoner's Dilemma Game on a spatial grid

Sub-Goals

1

Replicate findings from Helbing et al. (2011):
Unconditional imitation, success-driven migration, strategic noise
→ high levels of cooperation)

2

Extend model by adding “exemplary stationary leadership”
= ALL C strategy, punishment of defection and reward of cooperation

3

Test if exemplary leadership has additional beneficial effects for cooperation

Expectations

Clusters formerly developing randomly will evolve around leaders

Leadership will show positive effects on the number of cooperators beyond the effect of imitation & migration

(Parts of) the Model

Imitation

focal player – payoff comparison – strategy adoption in case of positive payoff difference

Success-driven migration

Mobility range M – test interactions – imitation

Leadership

Random placement in grid – always cooperate

$$P = P_{ii} = \begin{pmatrix} P_{11} & P_{12} & P_{13} \\ P_{21} & P_{22} & P_{23} \\ P_{31} & P_{32} & P_{33} \end{pmatrix} = \begin{pmatrix} R & S & x * R \\ T & P & 0 \\ R & S & R \end{pmatrix}$$

Noise

Random strategy mutations with probability q

Results I: Replication

Helbing et al.
(2011)

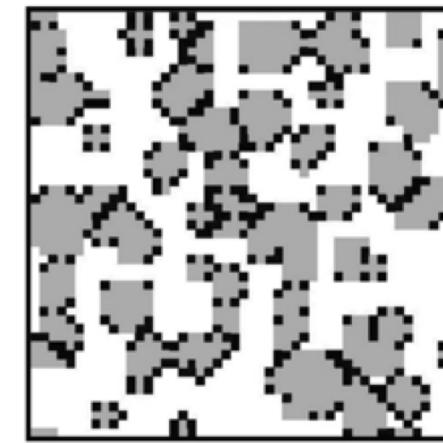
Imitation only



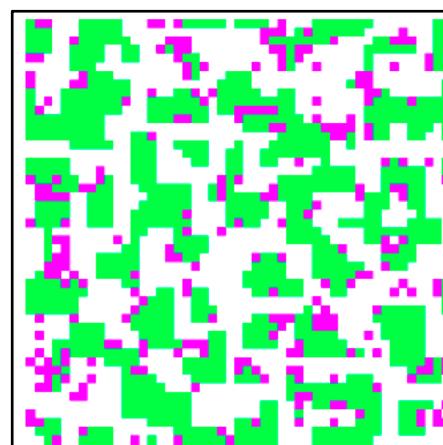
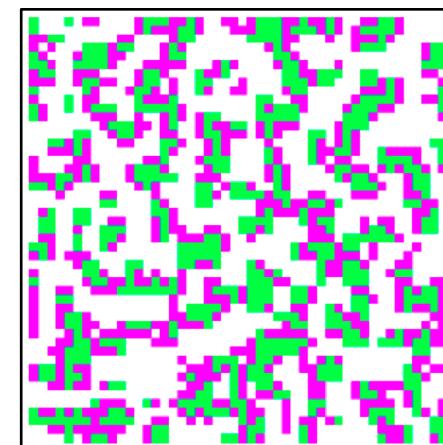
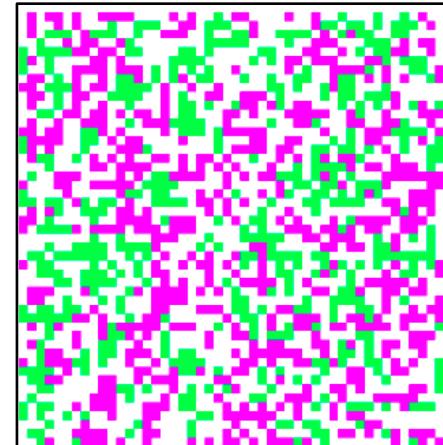
Migration only



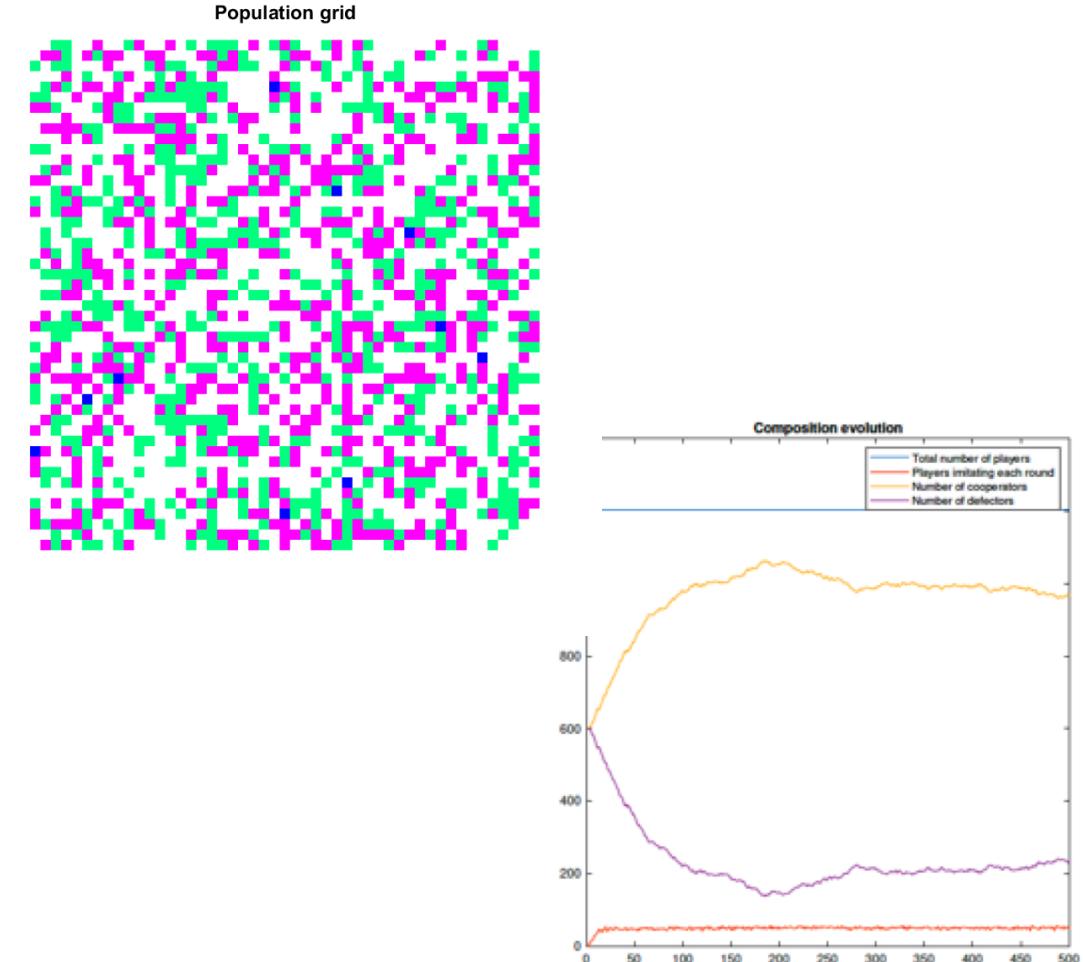
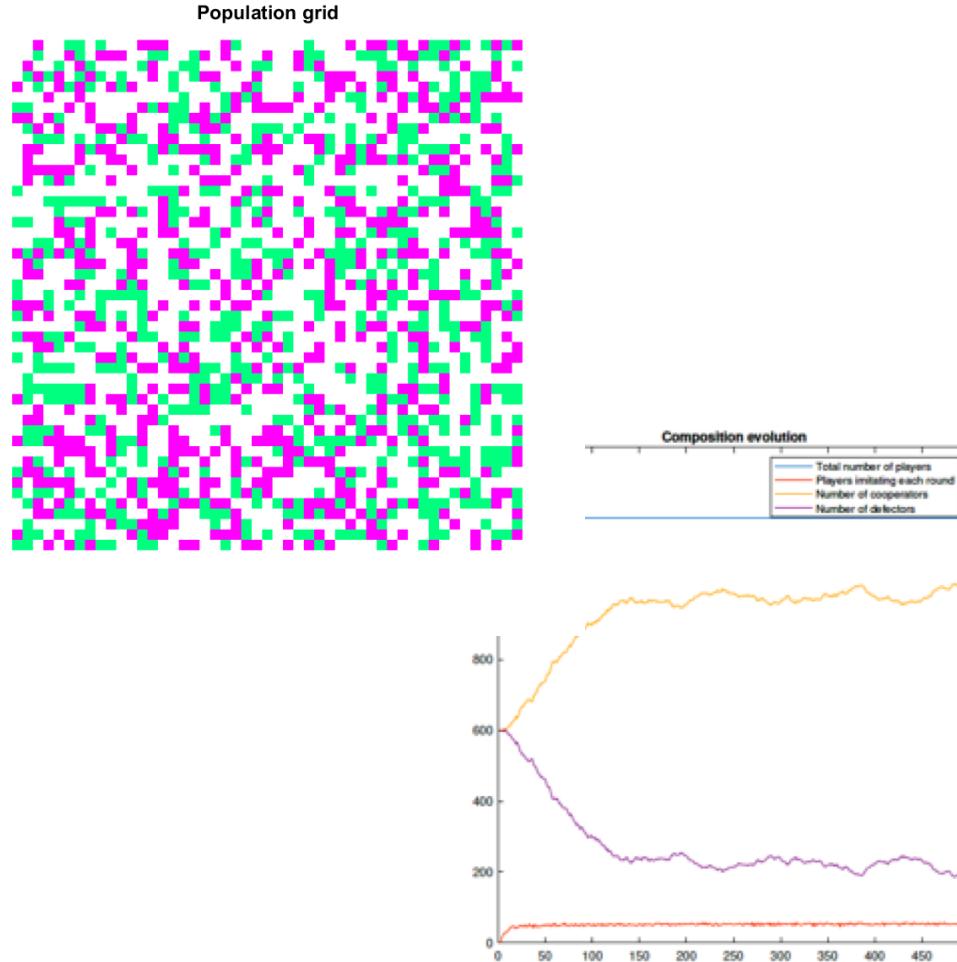
Both



Our results

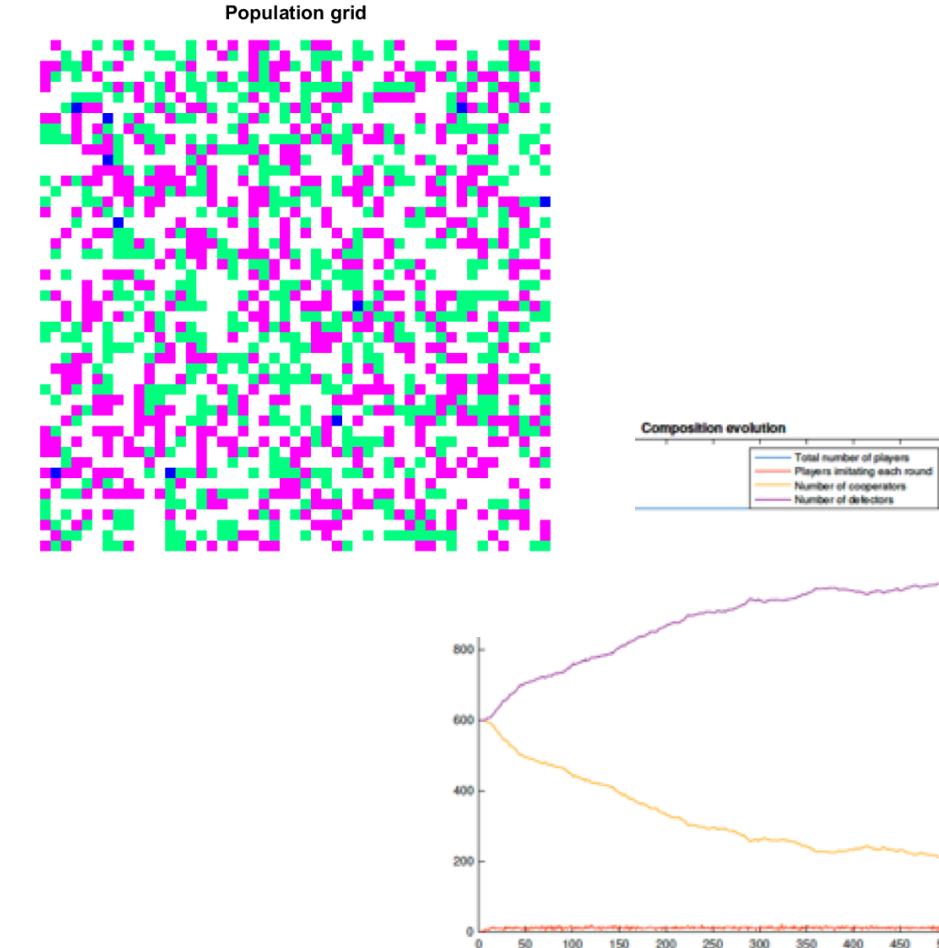
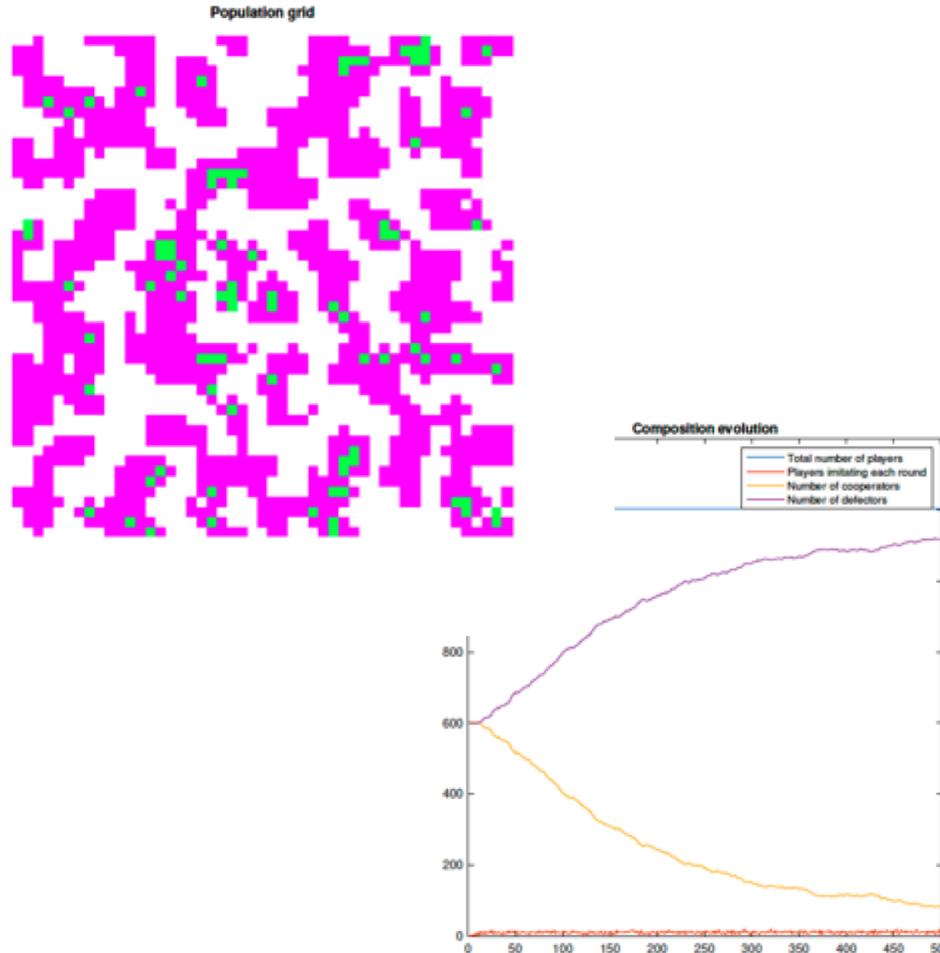


Results II: High Levels of Imitation/Migration with and without Leadership



Results III:

Low Levels of Imitation/Migration with and without Leadership



Discussion (Selection)

1. Cooperation evolves around leaders
2. Leadership keeps the dominating number of defectors at bay, protecting cooperation in scenarios where imitation and migration fail as mechanisms

Limitations

- We adjusted the payoff matrix quite drastically
- One could argue that the outcomes of leadership are rather related to reward and punishment, not to the “exemplary behaviour” of leaders

$$P = P_{ij} = \begin{pmatrix} P_{11} & P_{12} & P_{13} \\ P_{21} & P_{22} & P_{23} \\ P_{31} & P_{32} & P_{33} \end{pmatrix} = \begin{pmatrix} R & S & x * R \\ T & P & 0 \\ R & S & R \end{pmatrix}$$

Results presented are likely only a fraction of possible interesting dynamics and outcomes that can be created with our model

Summary & Outlook

Summary	
Replicate and extend findings from Helbing et al. (2011)	✓
Add “exemplary stationary leadership”	✓
Test if exemplary leadership has additional beneficial effects	✓
Clusters formerly developing randomly will evolve around leaders	(✓)
Leadership will show positive effects on the number of cooperators beyond the effect of imitation & migration	(✓)

Outlook

- Testing all combinations separately and systematically
- Testing different model parameter configurations
- Including other/even more mechanisms
- Implementation into other structures (networks) or application to other games (e.g. Hawk/Dove, Snowdrift, ...)
- Conduction of lab experiments on the basis of the model
- ...

Q&A

References

Dirk Helbing, Wenjian Yu, and Heiko Rauhut. Self-organization and emergence in social systems: Modeling the coevolution of social environments and cooperative behavior. *Journal of Mathematical Sociology*, 35(1-3):177–208, 2011.

Jalal Eddine Bahbouhi and Najem Moussa. A graph-based model for public goods with leaderships. *Applied Mathematics and Computation*, 349:53–61, 2019.

Backup Slide I: Pseudo-Code

```

input : Grid of size  $L \times L$ , density  $\rho$ , number of time steps  $t$ , sample size  $N$ ,  

neighborhood dimension  $m$ , mobility range  $M$ , initial ratio of  

cooperators, payoffs  $T/R/P/S$ , migration true/false, imitation  

true/false, leadership true/false, noise true/false  

output: The final spatial grid with cooperators and defectors after all interactions.  

initialization of the grid calling function init() with  $L$  and  $\rho$ ;  

for number of time steps t do  

    call function migration();  

    for sample size N do  

        if leadership then  

            | stationary leaders always cooperate;  

        end  

        1) play the Prisoners Dilemma game with  $T/R/P/S$  and update payoffs;  

    end  

    2) sum up payoffs in each neighborhood  $m$  calling function  

neighborhood_watch();  

    if migration then  

        3) do test-interactions on empty slots within mobility range  $M$ ;  

        if an empty slot has a higher payoff then  

            | 4) move to empty slot with higher payoff in mobility range  $M$ ;  

        end  

    end  

    if imitation then  

        5) imitate strategy of highest payoff within neighborhood  $m$  calling  

        function imitate();  

    end  

    if noise then  

        | 6) apply noise calling function noise();  

    end  

    update data and grid;  

end  

plot grid by calling function plot_pop();

```

Algorithm 1: *high-level pseudo-code abstraction*