



# The Emergence of Cooperation with Stationary Leadership

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# Introduction: Relevance of Studying Cooperation

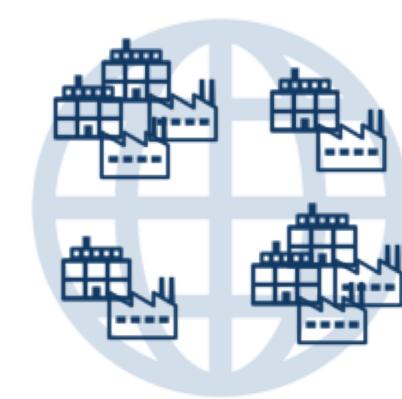
Defection is tempting because it guarantees «the largest payoff regardless of what the others are doing». (Dercole et al., 2019)



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)

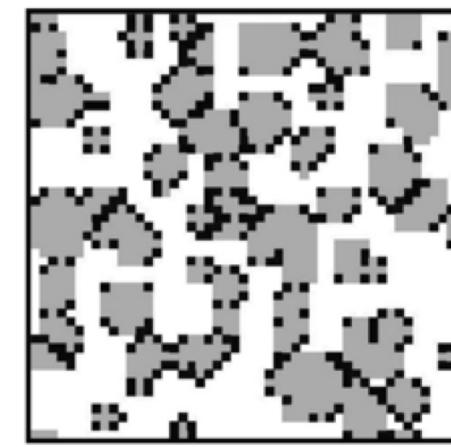
Imitation only



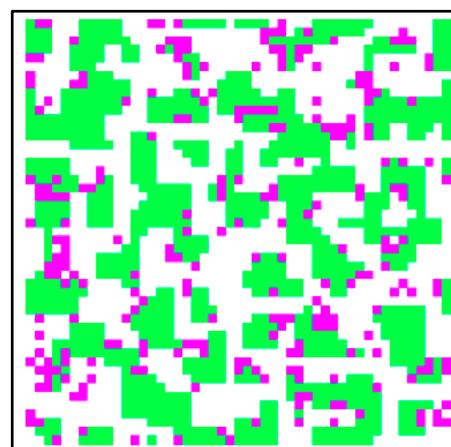
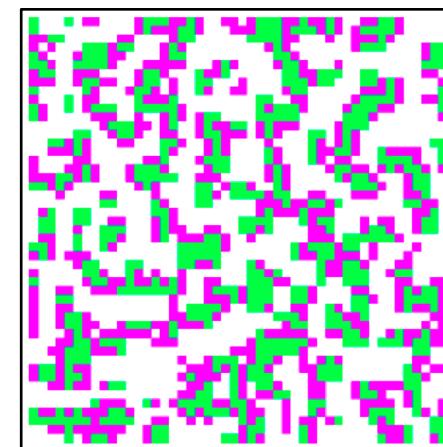
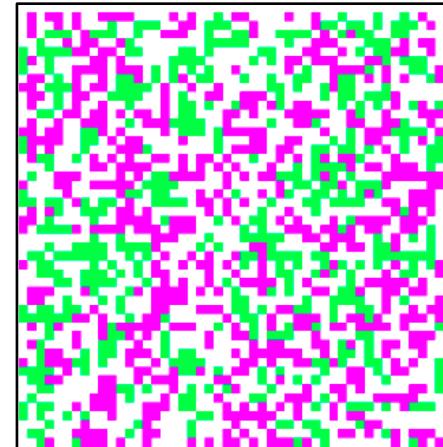
Migration only



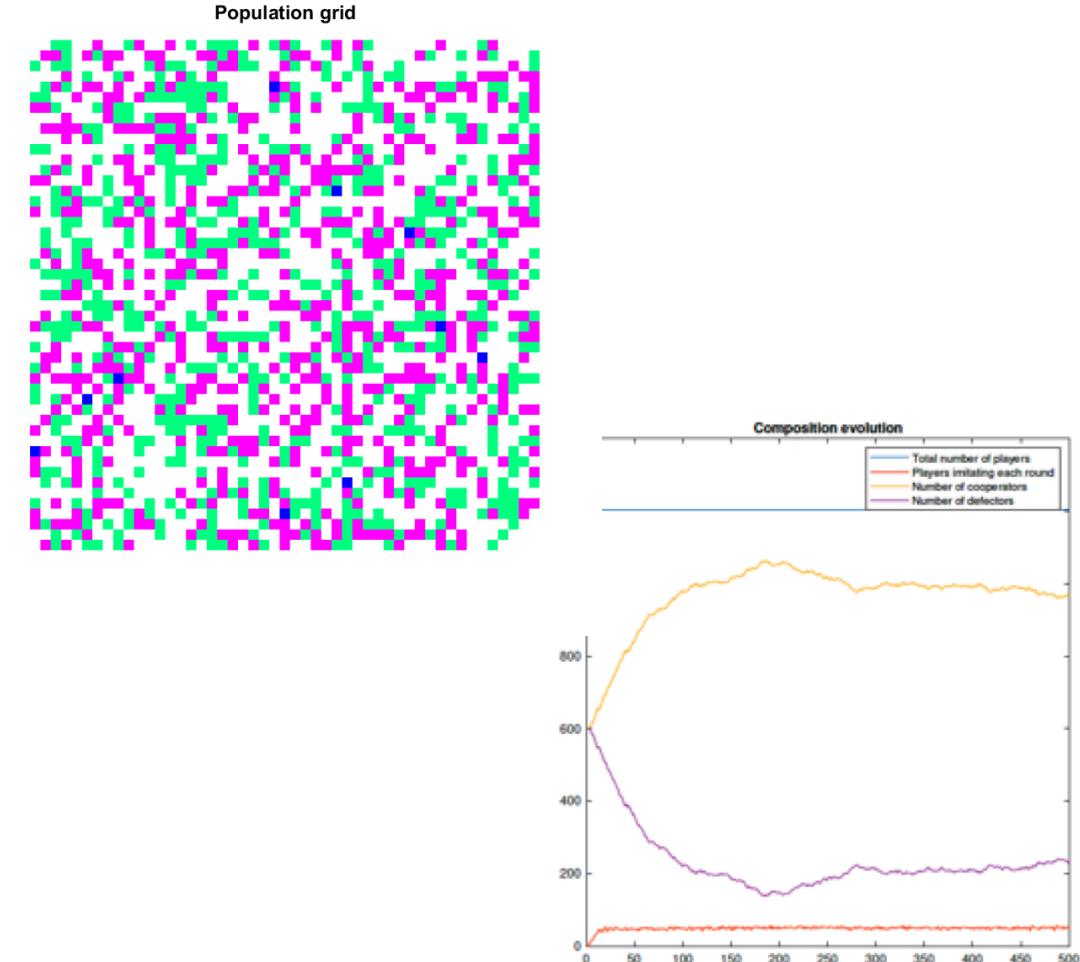
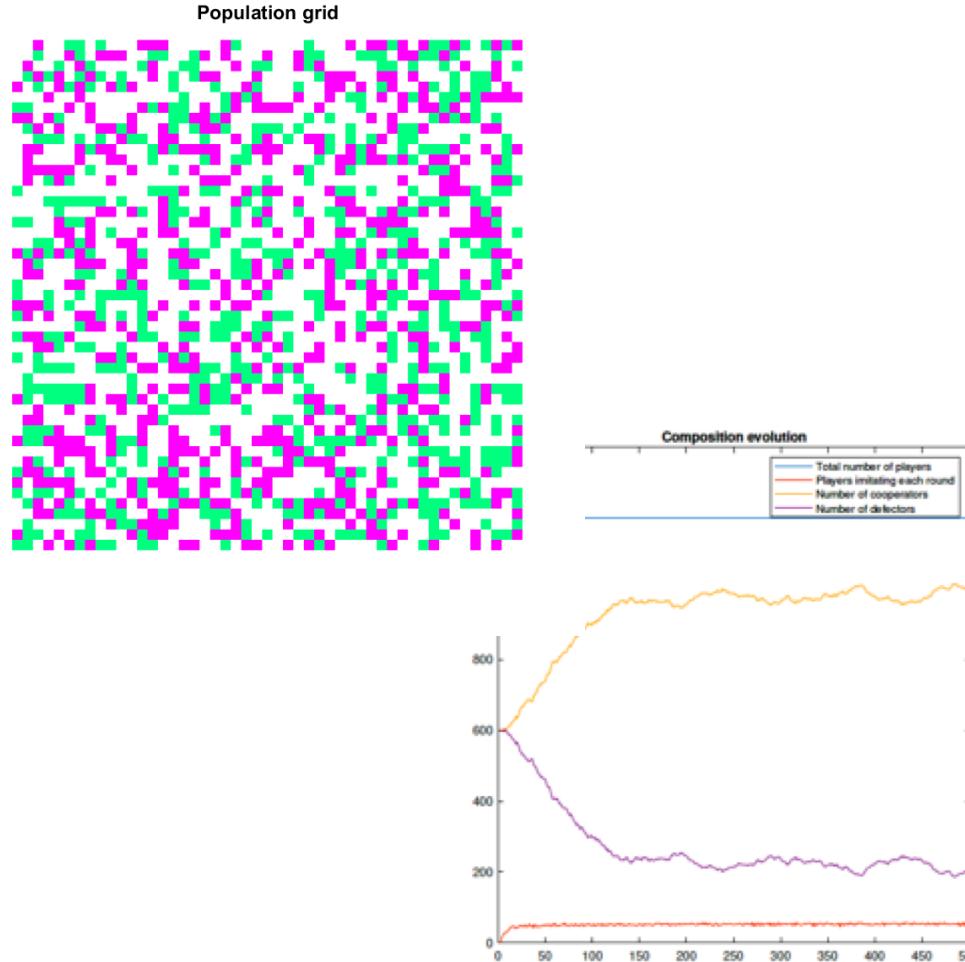
Both



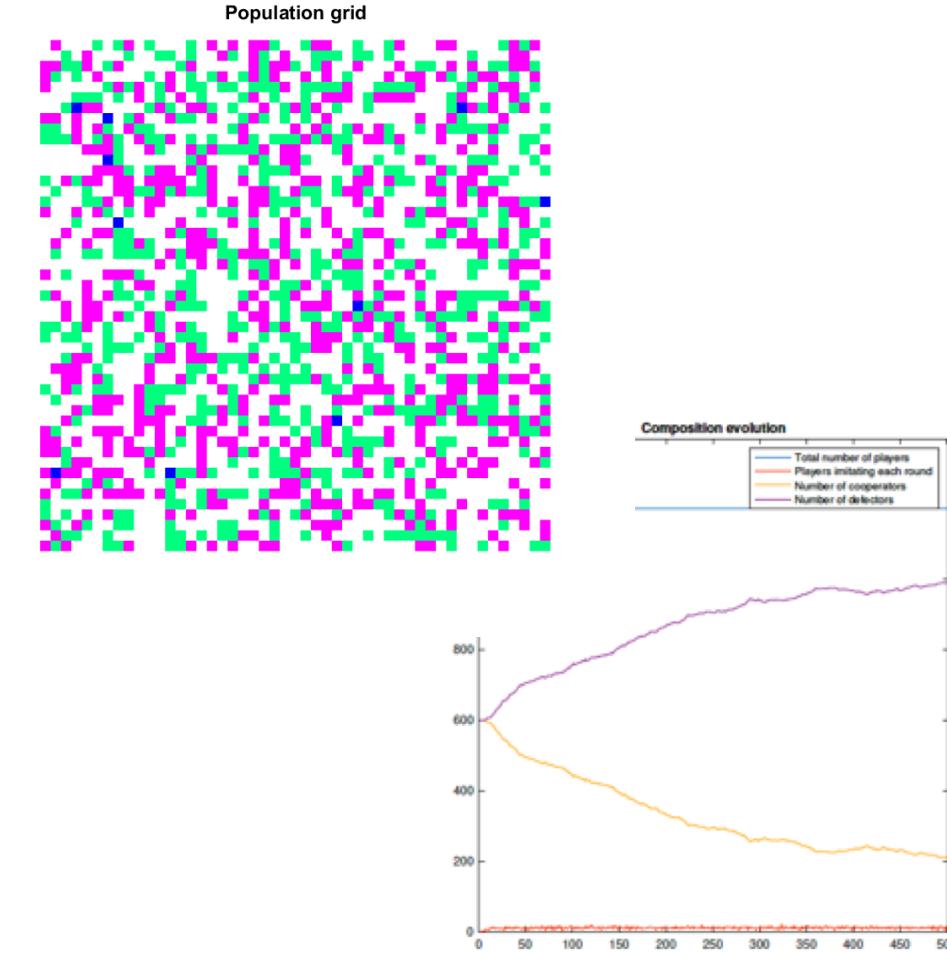
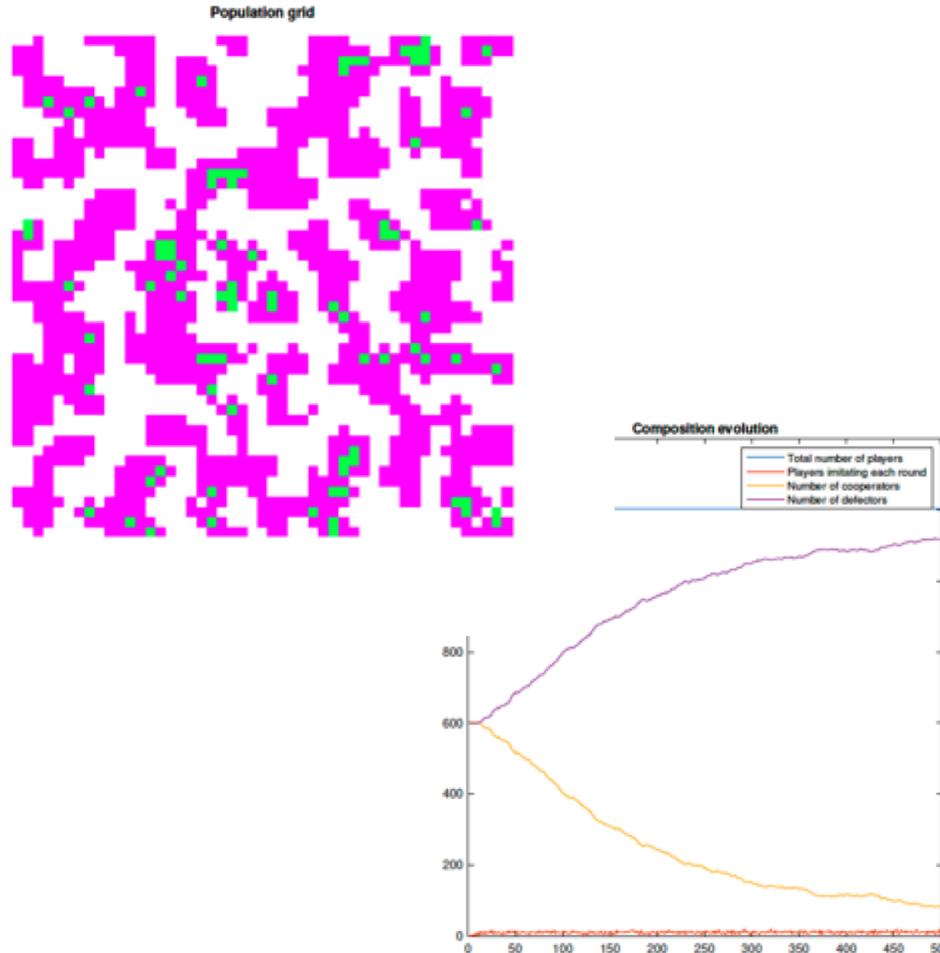
Our results



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



# Results III: Low Levels of Migration/Immitation 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

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

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*