

# Agent-Based Model for Iterative Prisoner's Dilemma

## Complex Social Systems - Project

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Decisions made under **collective rationality** may differ from those made under **individual rationality**.

## The Prisoner's Dilemma

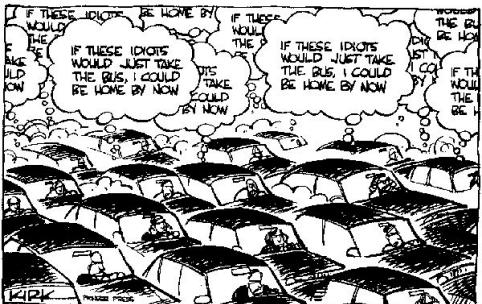
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# Prisoner's Dilemma is a Game Theory Illustration

Individuals, while **rational** and pursuing their **self-interest**, collectively make decisions that lead to **suboptimal outcomes**.

|                |                                  |                                  |
|----------------|----------------------------------|----------------------------------|
|                | A stays silent                   | A testifies                      |
| B stays silent | A gets 2 years<br>B gets 2 years | A walks free<br>B gets 10 years  |
| B testifies    | A gets 10 years<br>B walks free  | A gets 5 years<br>B gets 5 years |

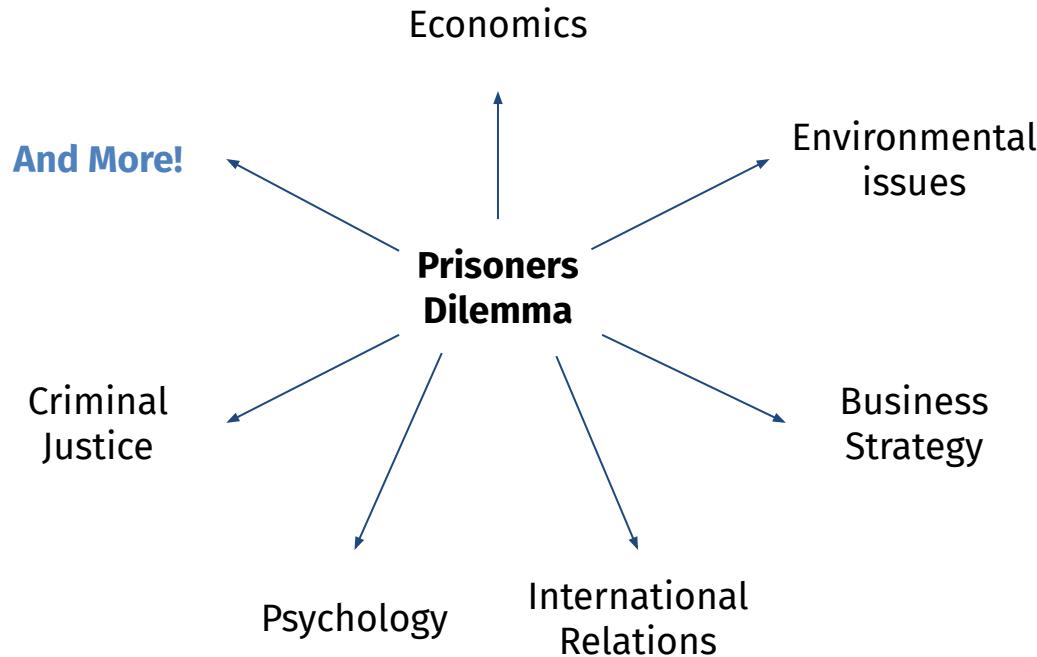
# Prisoner's Dilemma Models Social Dilemmas



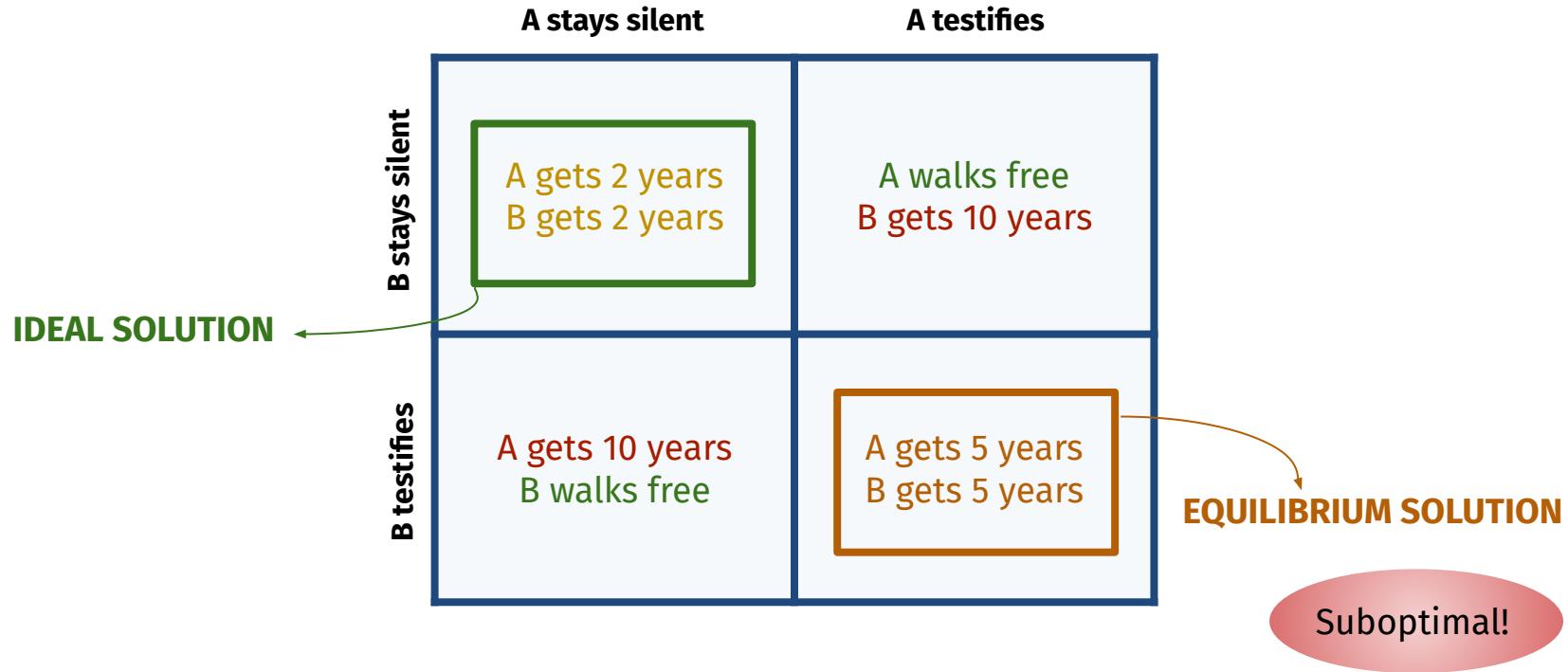
Individuals must  
balance **personal gain**  
with **cooperation for**  
**the greater good**



# Applications of Prisoner's Dilemma



# The Classical Prisoner's Dilemma



## Our Contributions/Variations

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# Limitation of the Classical Prisoner's Dilemma

Agents are often **adaptive**, i.e., they respond to their opponent's decisions, but they **do not evolve** and change their strategies.

## Classical strategies include:

- always play cooperation
- always play defection
- randomly play cooperation or defection
- cooperate until first defection, then only play defection
- start with cooperation/defection and mirror the opponent
- mirror the opponent until two defections in a row, then only play defection
- mirror the opponent but retaliate with two defections for every defection

# Evolution of Agents

Agents that can evolve strategy are closer to the real world.

Cooperative Agent



Defecting Agent

# Our Model - Evolution of Agents

Two components control an agent's behavior: its **strategy** and its **strategy switcher**.

A **strategy** determines the agent's next move and does not depend on an opponent's history.

A **strategy switcher** determines the agent's next strategy and depends on an opponent's history.

An opponent's complete history is not available to every agent, rather it relies on **crowd knowledge**.

Agents only interact with a few other neighbors.

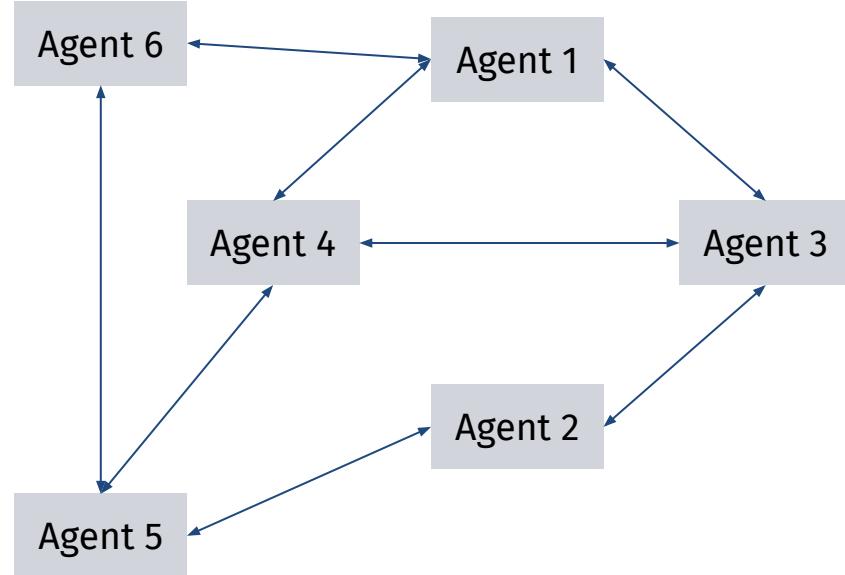
# Iterative Prisoner's Dilemma - Evolving Agents Play Multiple Rounds



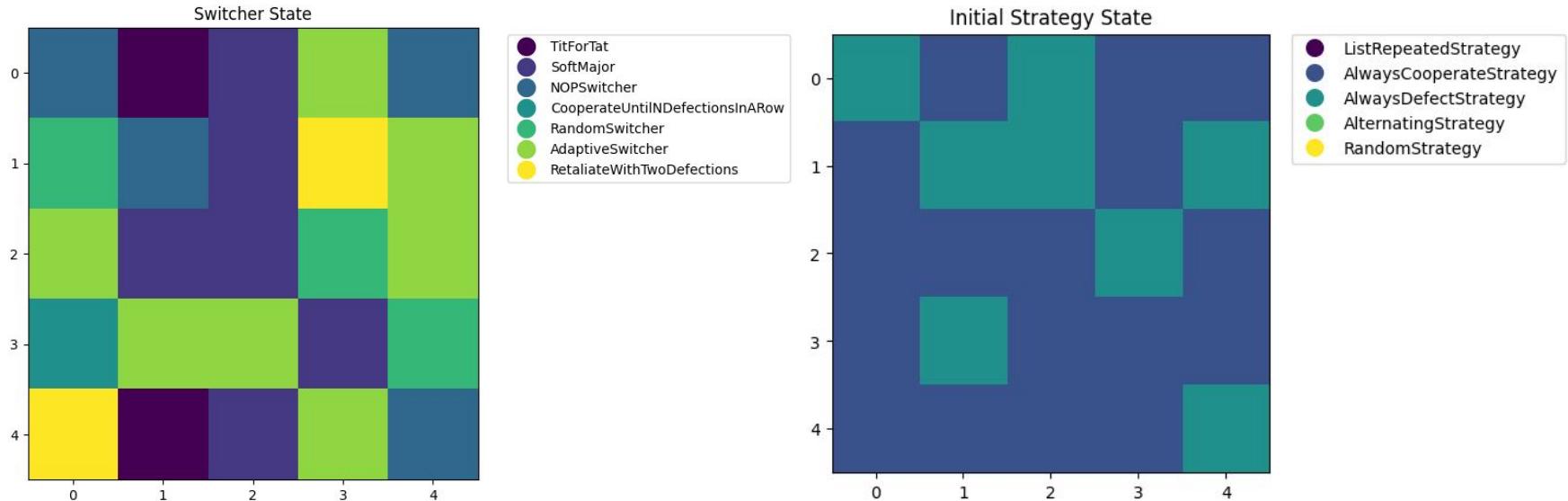
and so on...

# Increasing Number of Players - Networks

Next, we create a **network** of players, increasing number of players from 2 to (potentially) hundreds



# Our Model

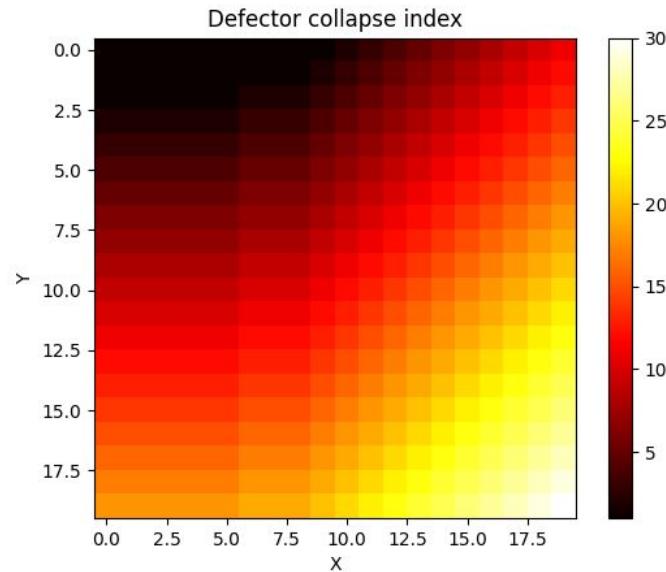


## Running Iterated Prisoner's Dilemma in our Model

In every round, **every pair** of connected agents play in a **sequential order**, so an agent can potentially evolve multiple times per round.

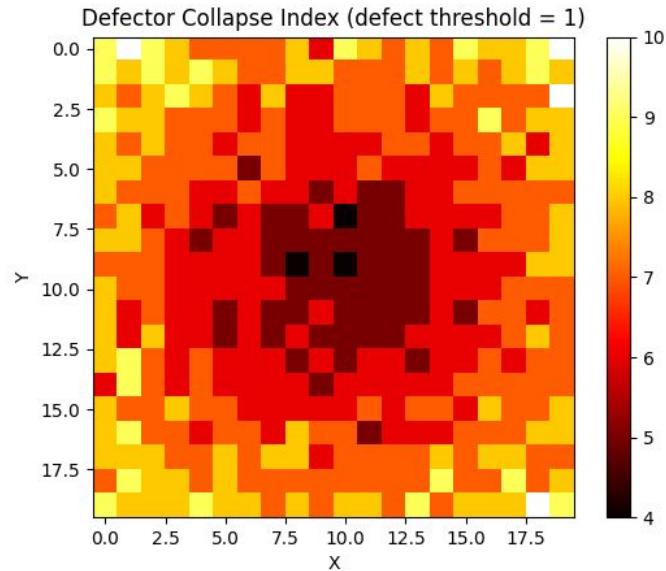
# Peculiarities of our Model

But sequential execution of games in the grid leads to undesirable patterns like these...



# Peculiarities of our Model

So we **randomize** the order in which games are played in **each round**.

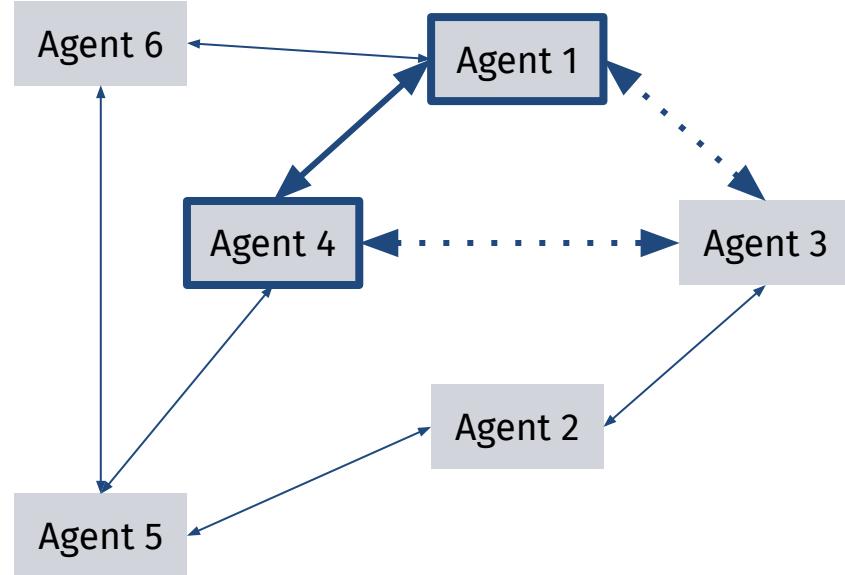


# More Features in our Model - Community Knowledge

Agents can not switch strategy based on **player history**, because that is **not available**

Agents can only switch strategy based on **community knowledge from neighbors** about opponent's history

Community knowledge may **not be completely up-to-date** and may not transfer fully on demand in time, reflecting real-life scenarios

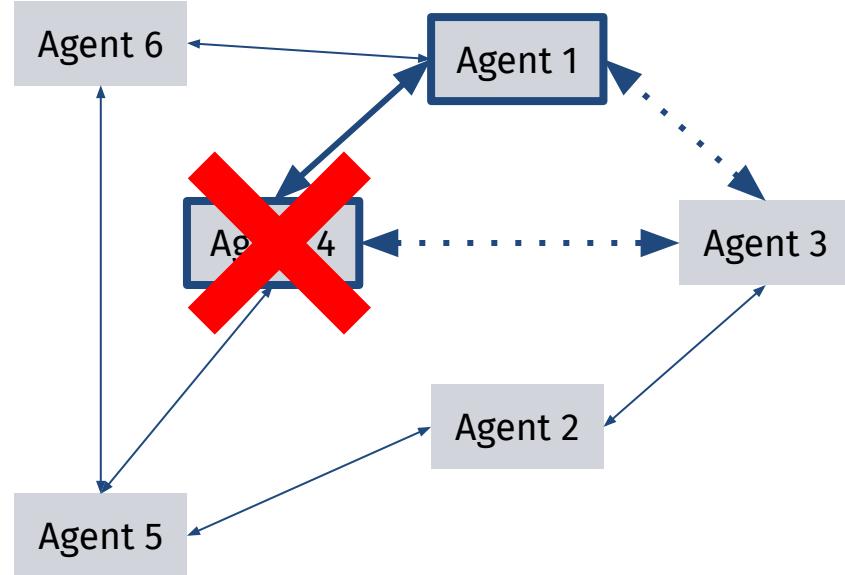


# More Features in our Model - Credit

Players **gain or lose credit** according to payoff matrix

In real-life scenarios, players only get **limited opportunities** to play

Players with negative credit are treated as **dead**

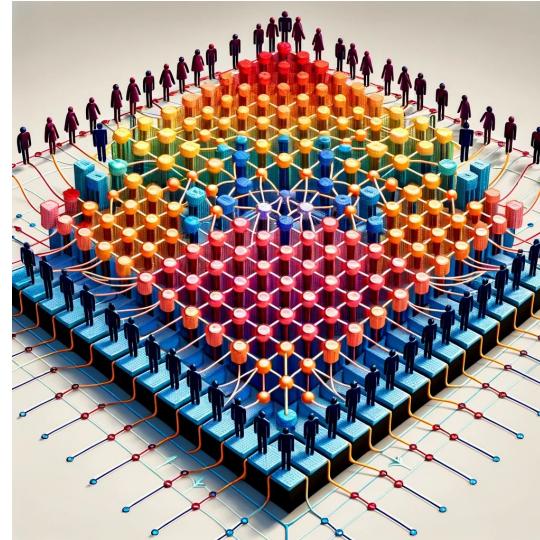


## Some Experiments

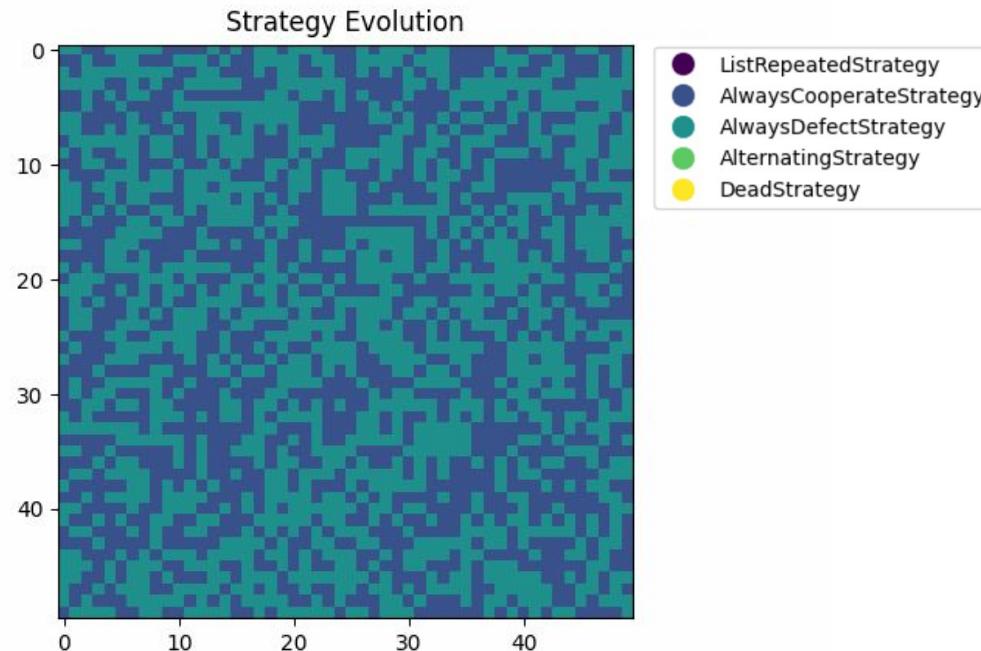
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# Experiment 1: Mimicry in a Neutral Population

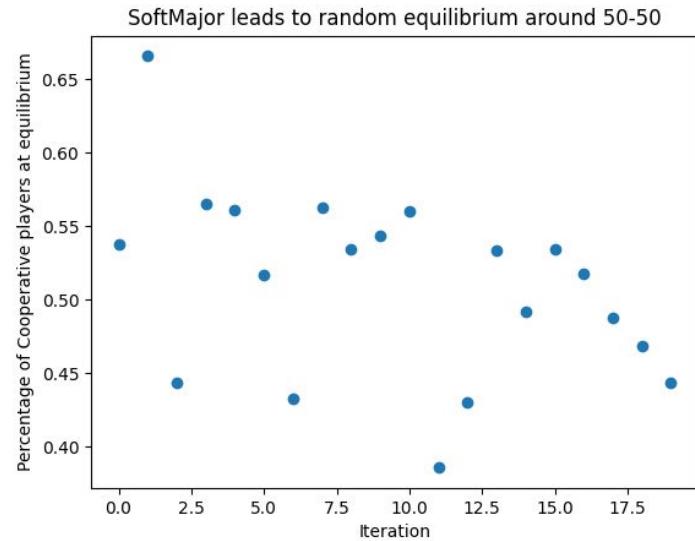
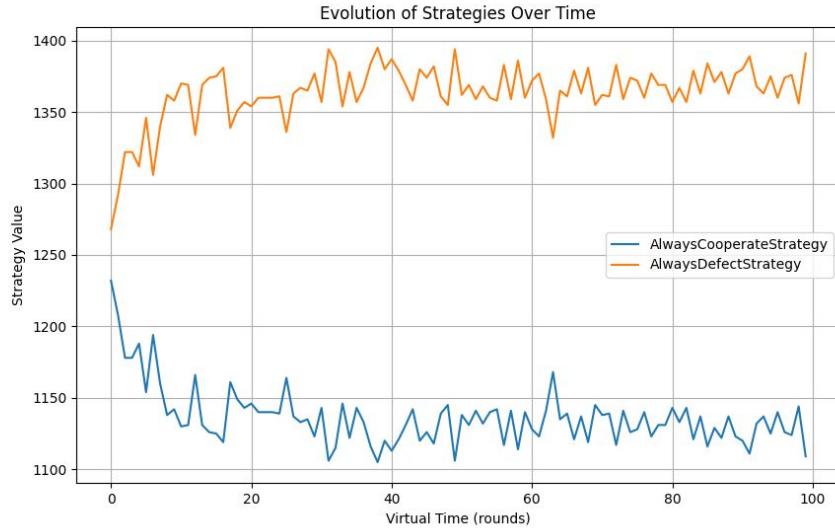
- **Initial Population:** Evenly divided between cooperators and defectors.
- **Strategy Adaptation:** Individuals mimic the strategies of the majority.



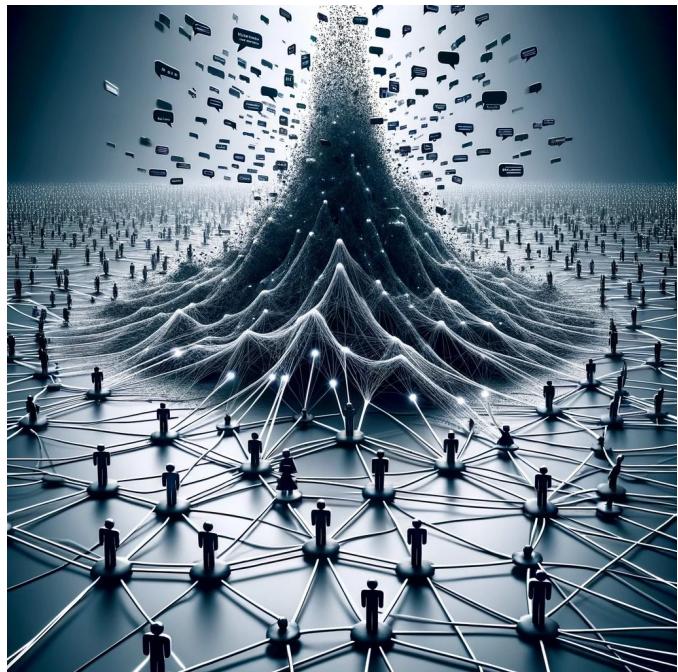
# Experiment 1: Mimicry in a Neutral Population



# Experiment 1: Mimicry in a Neutral Population



## Experiment 2: Minority-Induced Behavioral Cascade



The spread of misinformation



Panic selling in a financial market

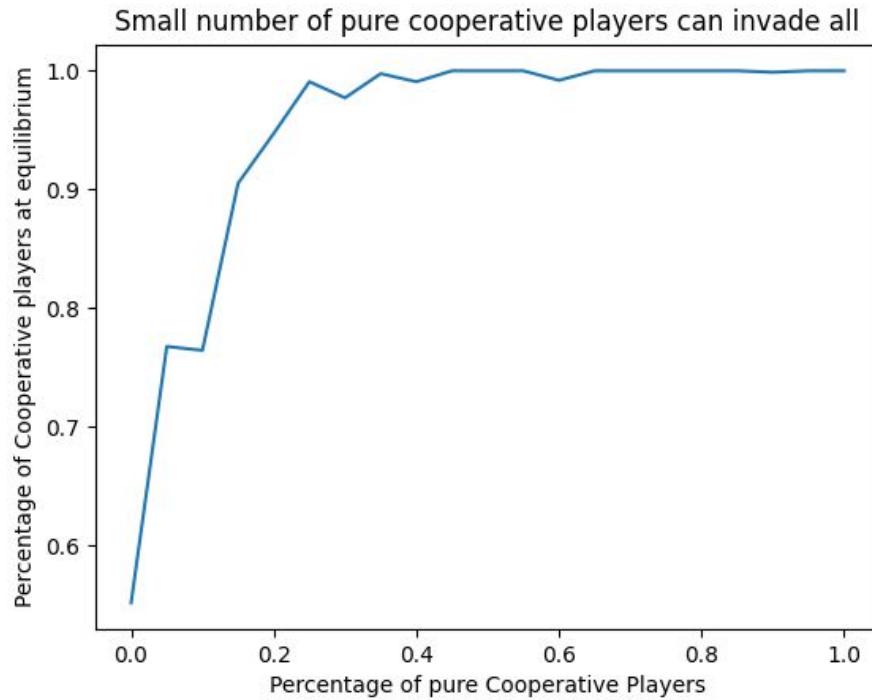
## Experiment 2: Minority-Induced Behavioral Cascade

- **Initial Population:** Evenly divided between cooperators and defectors. Small number of defective players never change.
- **Strategy Adaptation:** Individuals mimic the strategies of adjacent participants.

## Experiment 2: Minority-Induced Behavioral Cascade



## Experiment 2: Minority-Induced Behavioral Cascade



## Experiment 3: Bayesian Thinking in a Neutral Population



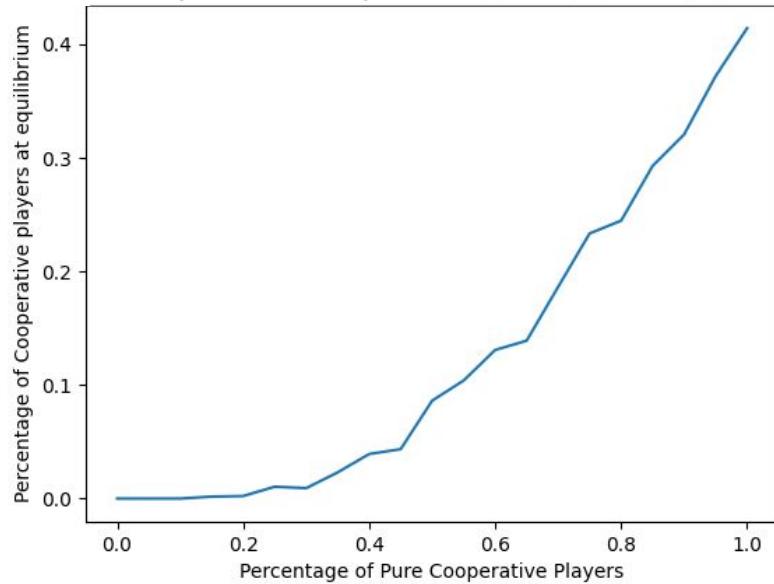
Bayesian buy/sell decisions

## Experiment 3: Bayesian Thinking in a Neutral Population

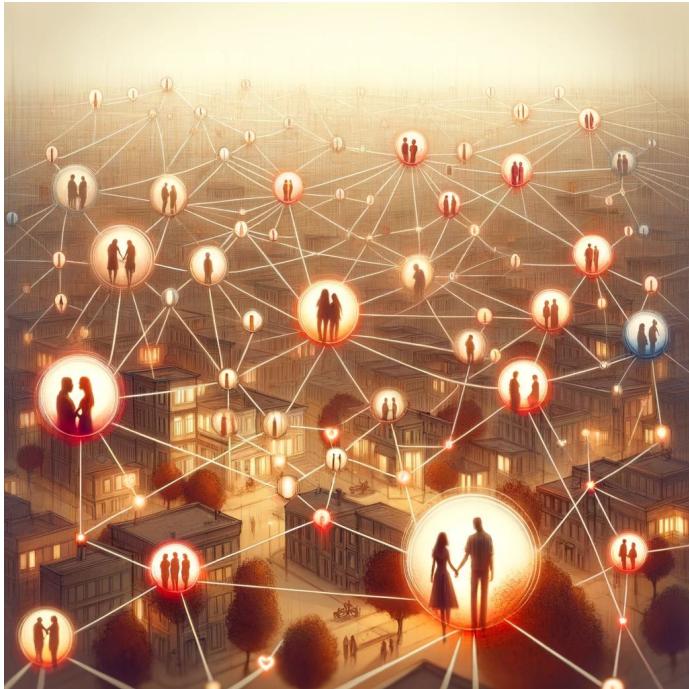
- **Initial Setup:** Population evenly split between cooperative and defective players.
- **Strategy Adaptation:** Strategy updates based on Bayesian analysis of opponent's (accessible) history. Decisions influenced by weighing risks and rewards from the payoff matrix.

## Experiment 3: Bayesian Thinking in a Neutral Population

Pure Cooperative % vs Cooperative % at Equilibrium ( $C/C = 2$ ,  $C/D = -1$ ,  $D/C = 3$ ,  $D/D = 1$ , Lattice)



## Experiment 4: Pure Defectors in a Cynical Cooperative Population

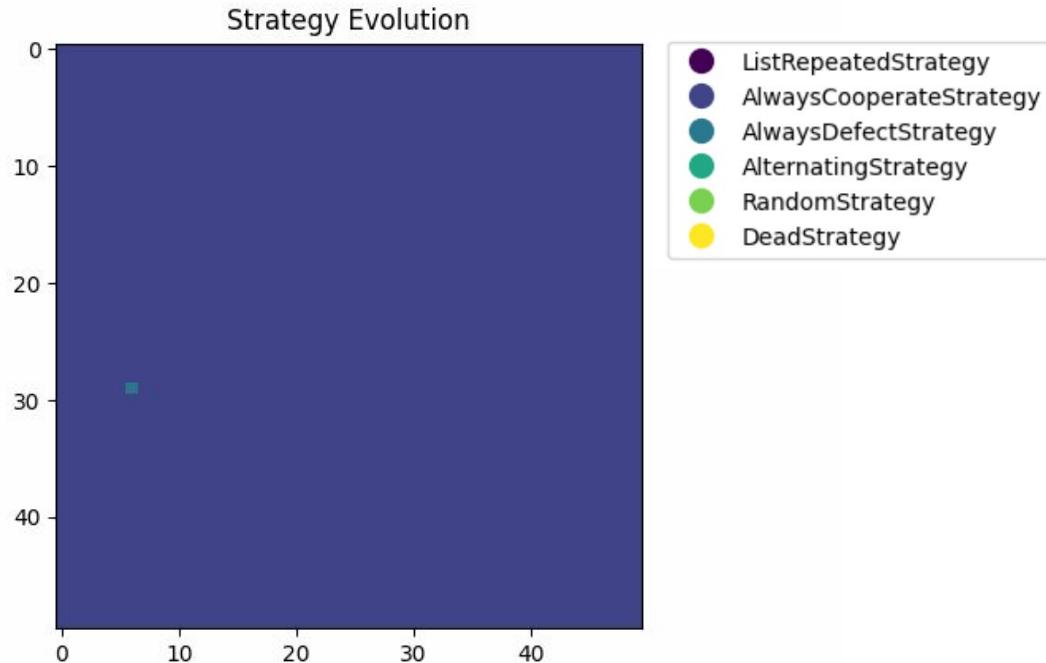


Impact of a few defectors on interpersonal dynamics

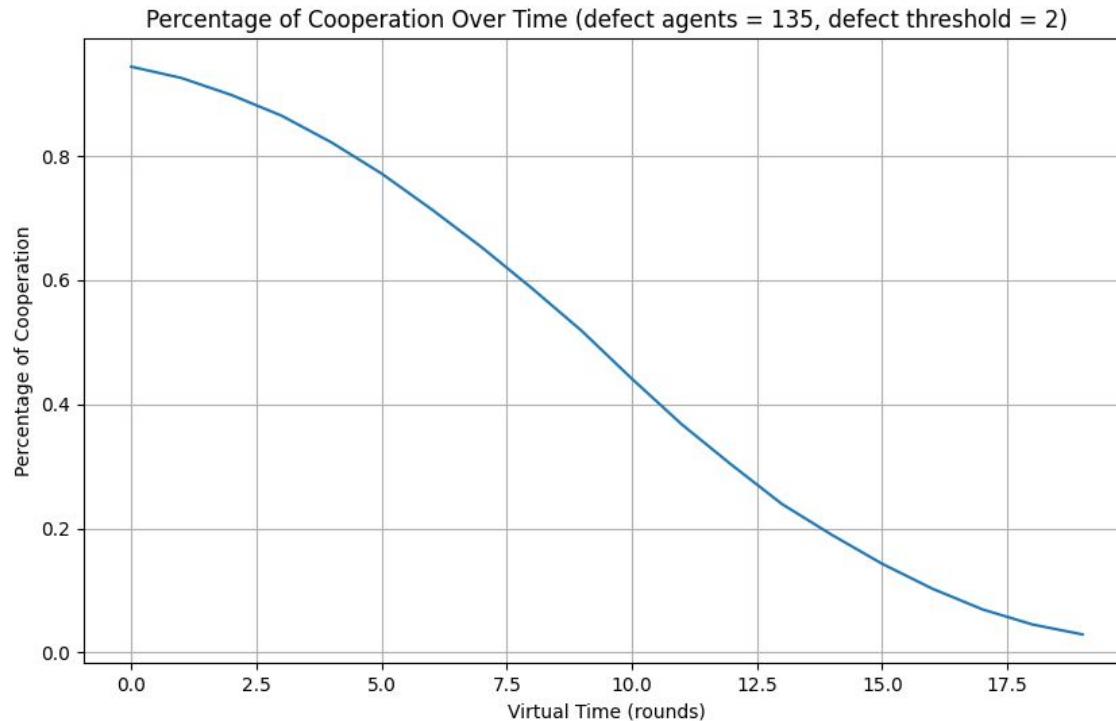
## Experiment 4: Pure Defectors in a Cynical Cooperative Population

- **Initial Condition:** Majority cooperative, with a small number  $n$  of defectors.
- **Strategy Adaptation:** Players stay cooperative until betrayed  $x$  times consecutively, then they become defective.

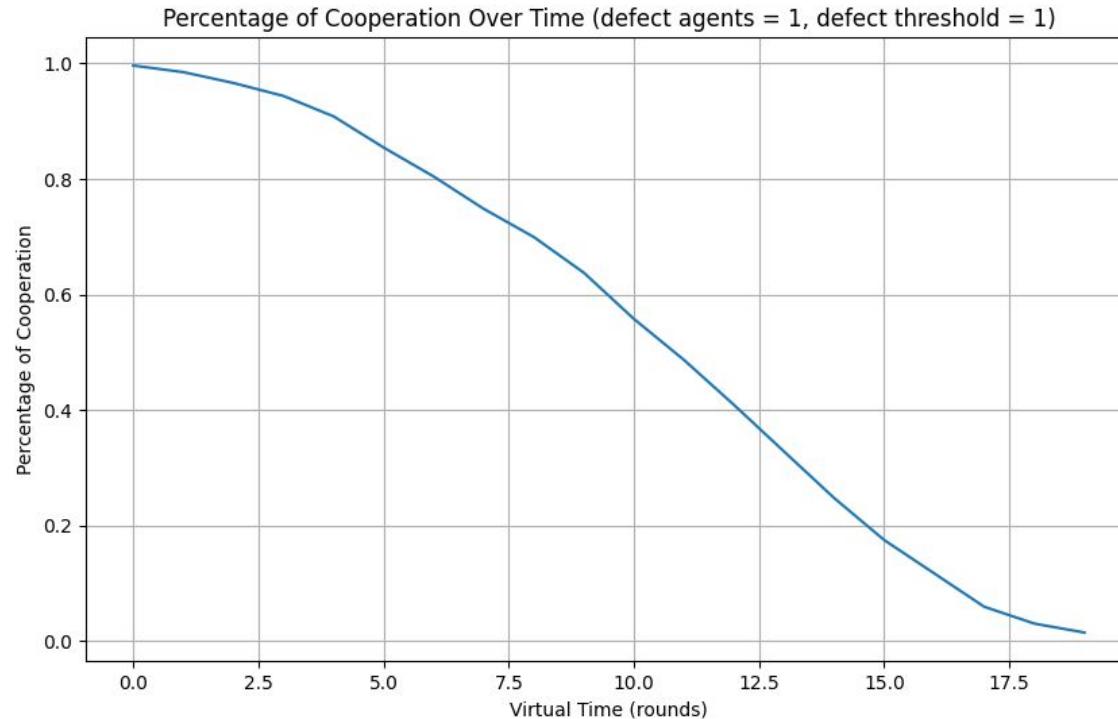
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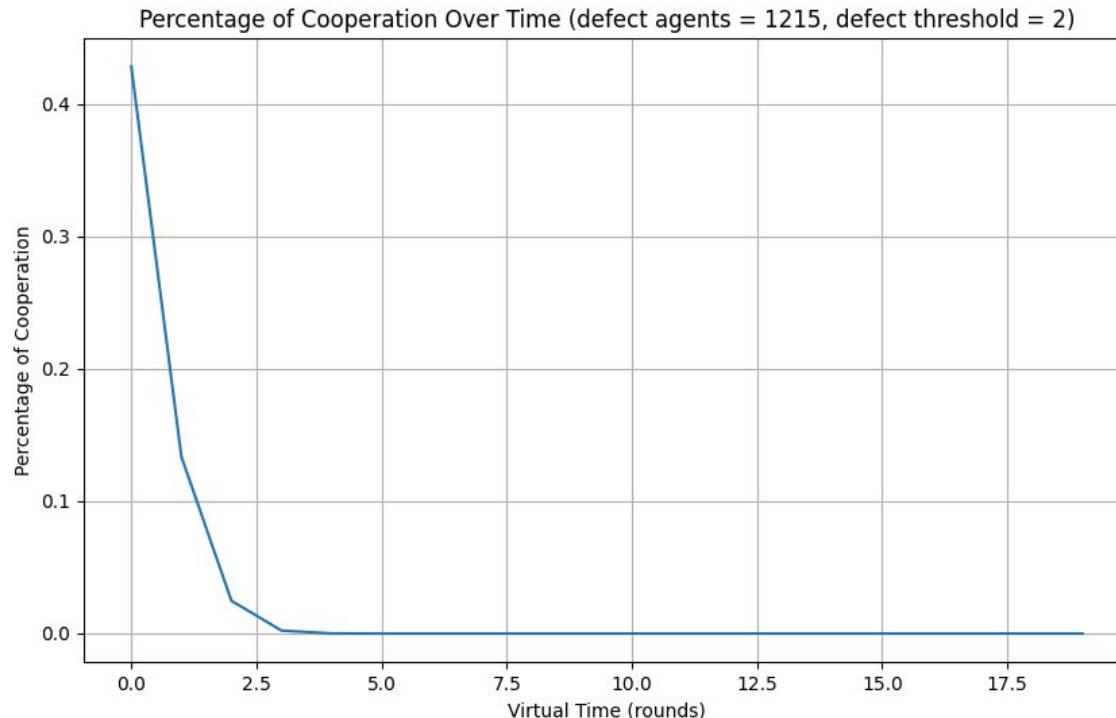
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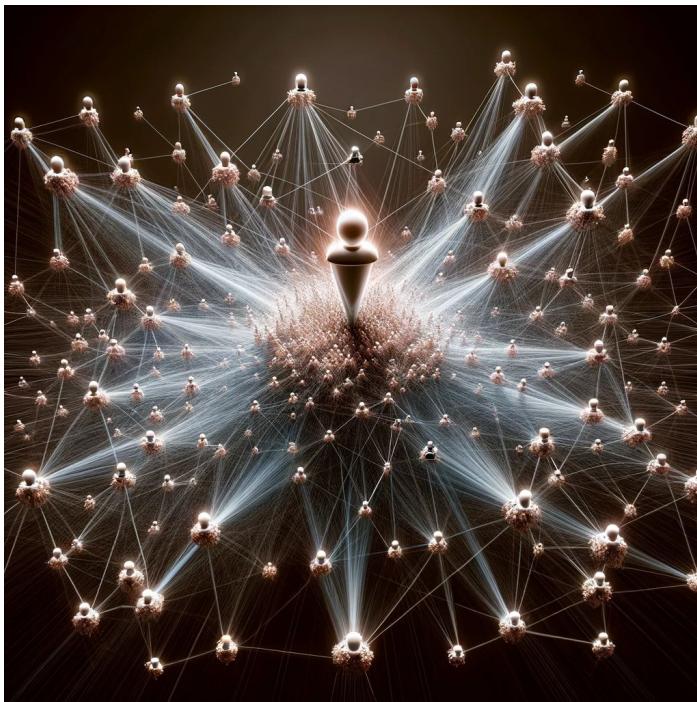
## Experiment 4: Pure Defectors in a Cynical Cooperative Population



## Experiment 4: Pure Defectors in a Cynical Cooperative Population



## Experiment 5: Single Defector in a Network - Impact Analysis

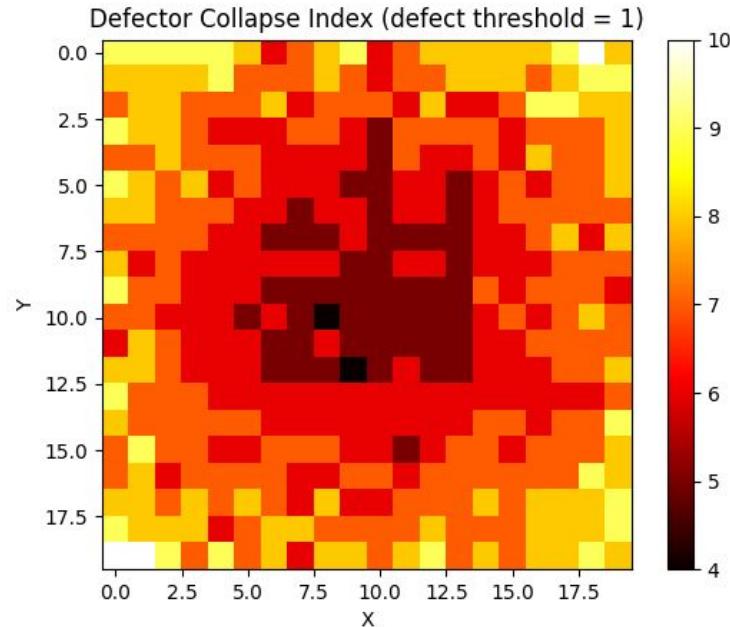
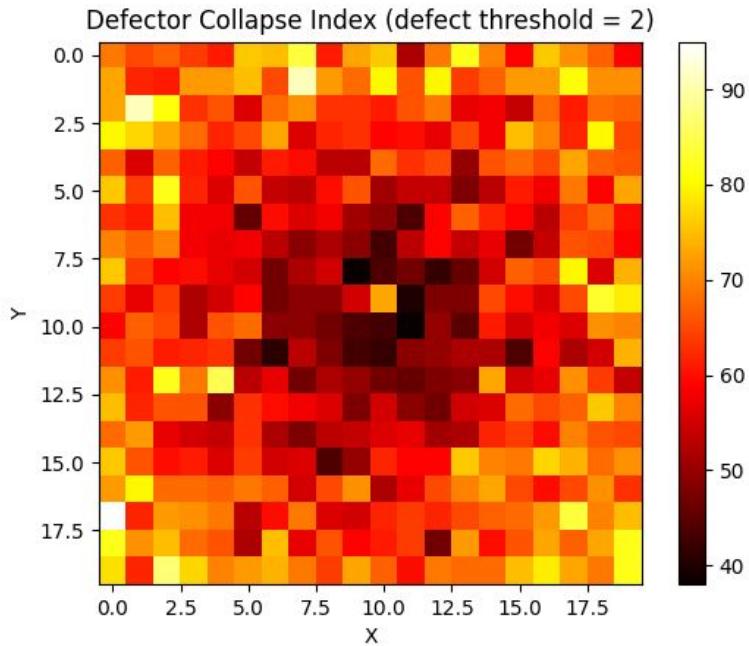


Impact of high-influence node defectors

## Experiment 5: Single Defector in a Network - Impact Analysis

- **Initial Condition:** All players cooperative except for one defector.
- **Strategy Adaptation:** Players stay cooperative until betrayed  $x$  times consecutively, then they switch to 'defect'
- **Variable:** Single defector positioned at various locations.
- **Collapse Index Measurement:** Number of steps until less than 10% of players remain cooperative.
- **Investigation Focus:** Impact of defector's initial location on the speed of system collapse.

## Experiment 5: Single Defector in a Network - Impact Analysis

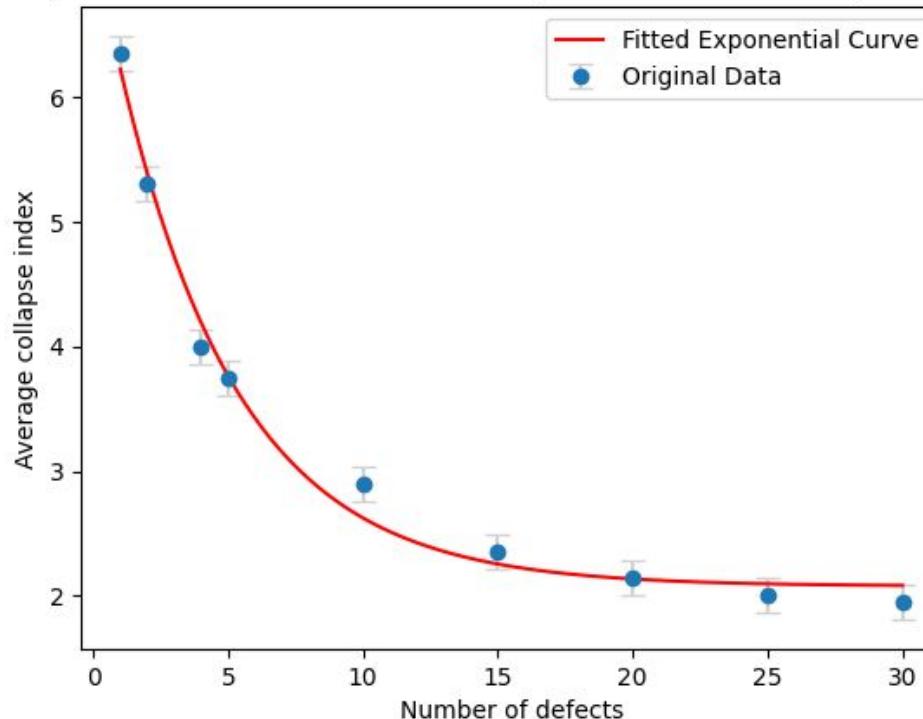


## Experiment 6: Defector Density's Impact Analysis

- **Initial Condition:** All players cooperative except for one defector.
- **Strategy Adaptation:** Players stay cooperative until betrayed  $x$  times consecutively, then they switch to 'defect'
- **Variable:** Vary the number of defectors  $n$  in the network.
- **Iteration Averaging:** Average the results over multiple iterations for each  $n$  (randomly distributed in each iteration).
- **Focus:** Investigate the relationship between the collapse index and the number of defectors  $n$ .

## Experiment 6: Single Defector's Impact Analysis

Average Collapse Index vs Number of Randomly Distributed Defects (defect threshold = 1)



# Experiment 7: Incentives Determine Survival Fitness



Business tactics shaped by Economic and Market context



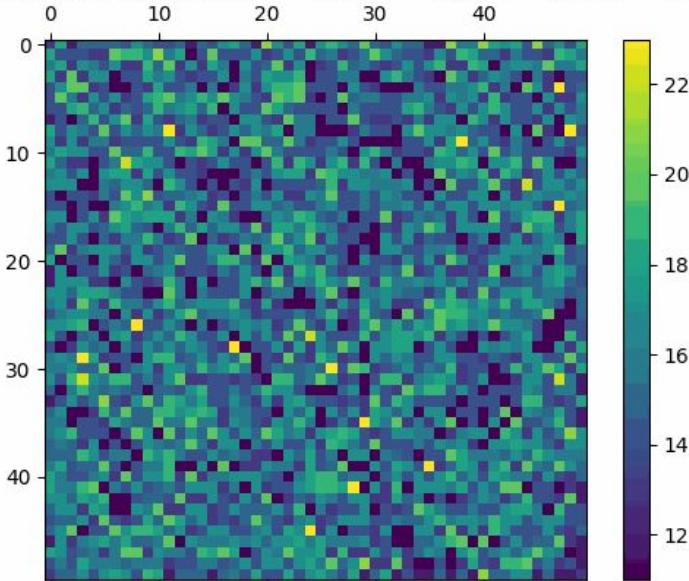
Dating approaches influenced by cultural norms

## Experiment 7: Incentives Determine Survival Fitness

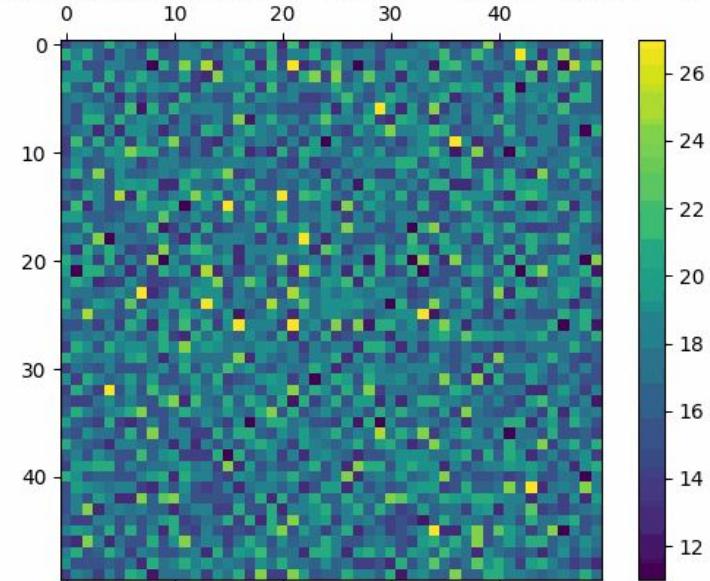
- **Initial Condition:** Start with a 50-50 mix of cooperative and defective players. Each player receives a random meta strategy for switching between strategies.
- **Equal Credit Allocation:** All players begin with the same number of credits.
- **Survival Rate Analysis:** Investigate the survival rate of different meta strategies over time for different payoff matrices.

## Experiment 7: Incentives Determine Survival Fitness

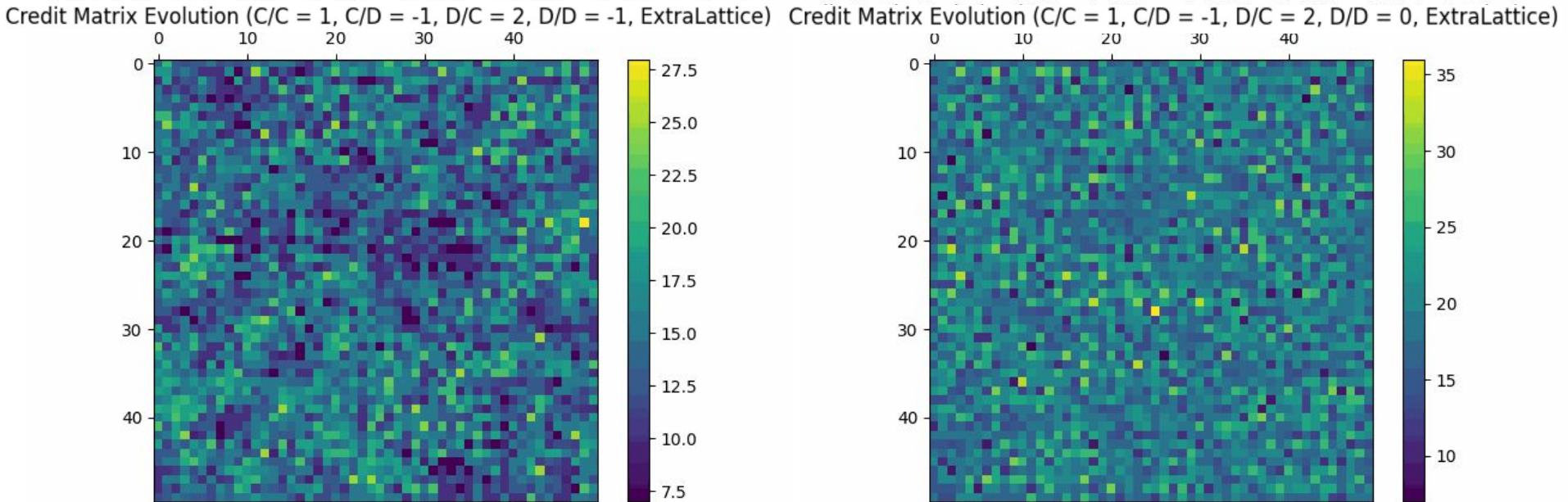
Credit Matrix Evolution ( $C/C = 1$ ,  $C/D = -1$ ,  $D/C = 2$ ,  $D/D = -1$ )



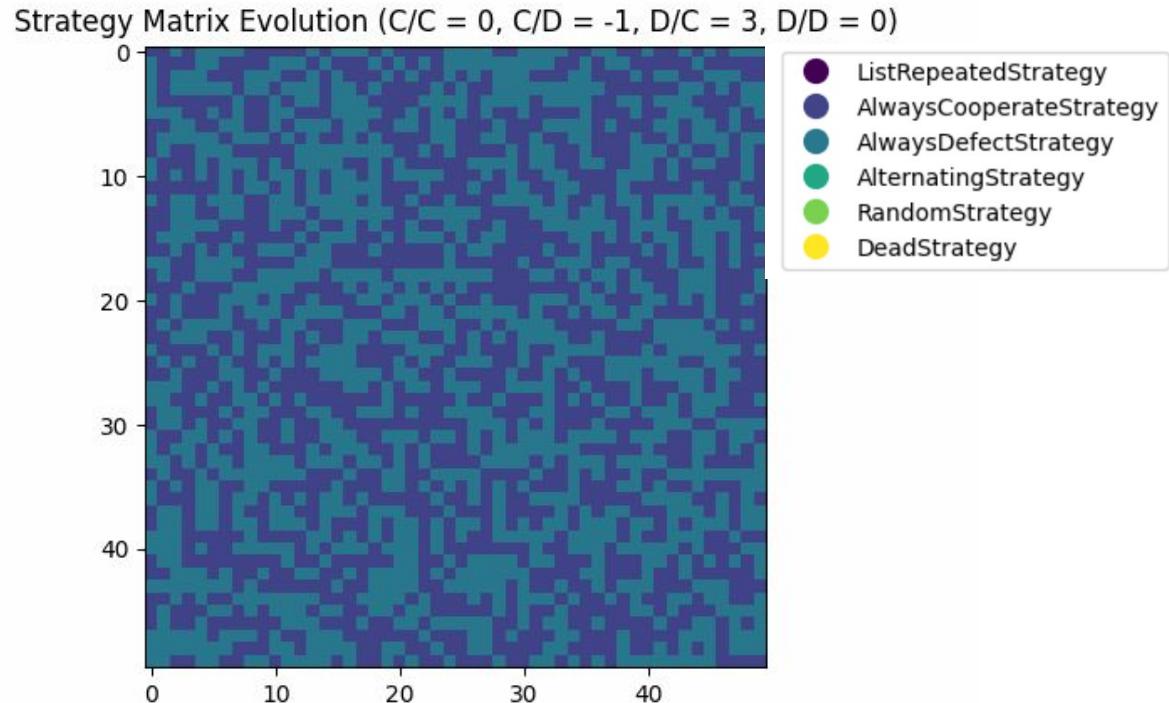
Credit Matrix Evolution ( $C/C = 1$ ,  $C/D = -1$ ,  $D/C = 3$ ,  $D/D = 0$ )



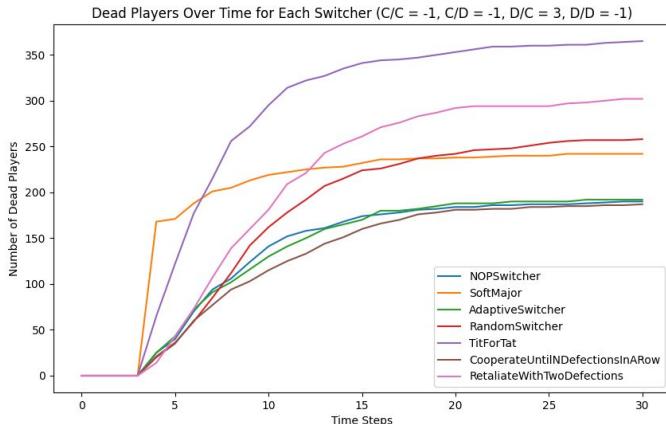
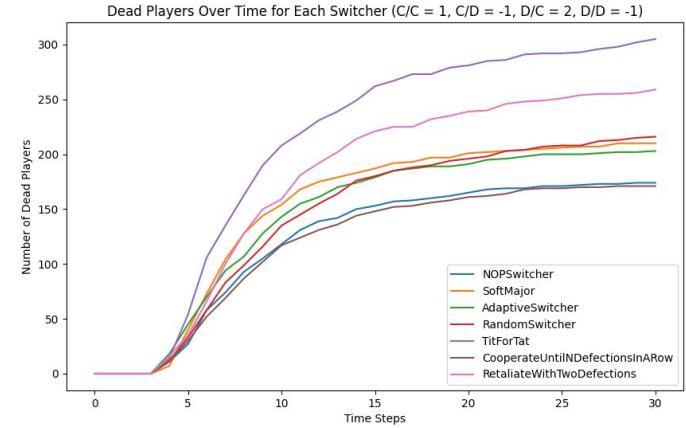
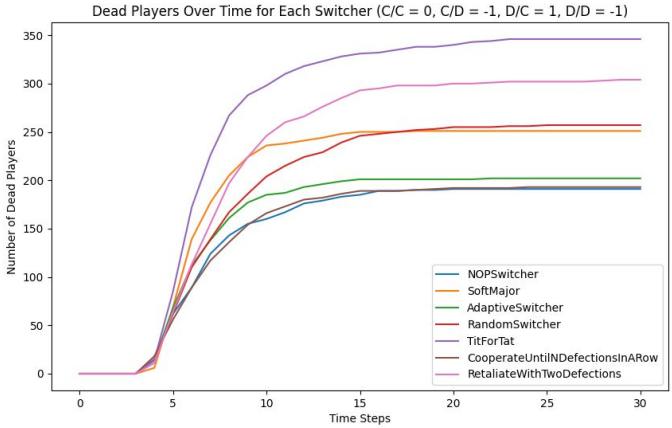
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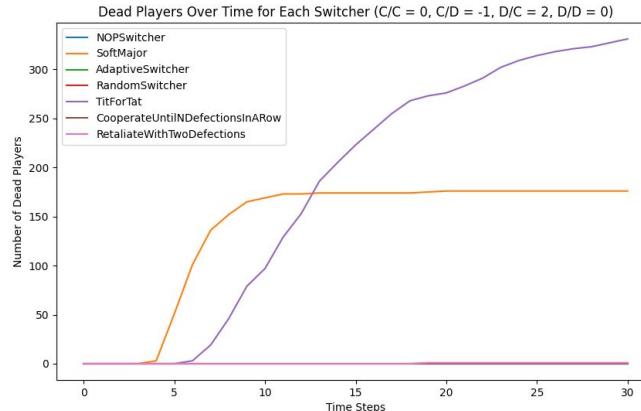
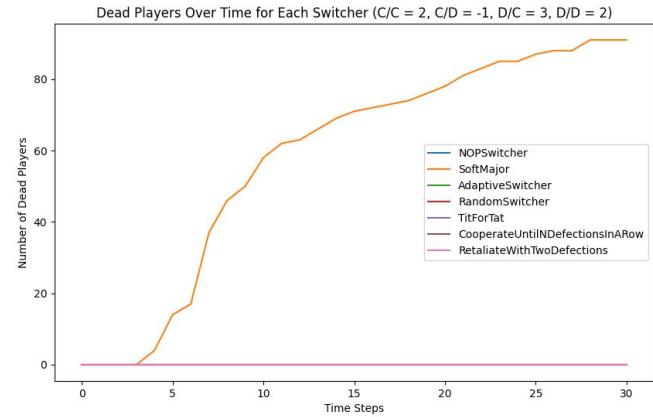
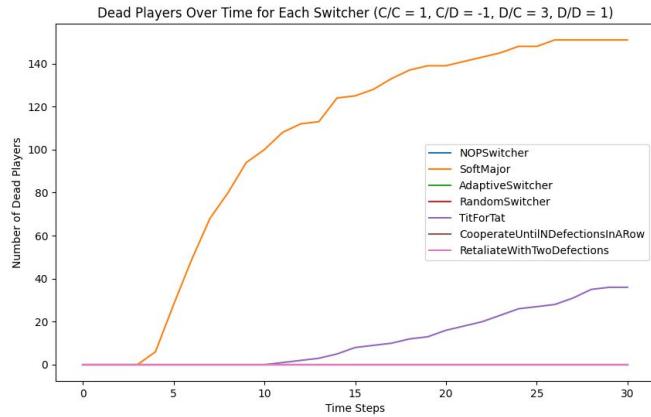
## Experiment 7: Incentives Determine Survival Fitness



# Experiment 7: Incentives Determine Survival Fitness



# Experiment 7: Incentives Determine Survival Fitness



# Is This The End?

*"If only it were all so simple! If only there were evil people somewhere insidiously committing evil deeds, and it were necessary only to separate them from the rest of us and destroy them. But the line dividing good and evil cuts through the heart of every human being. And who is willing to destroy a piece of his own heart?"*

**Aleksandr Solzhenitsyn, *The Gulag Archipelago 1918–1956***