Observing Cascading Failure Effect in Large Socio-Economic Network Systems through the Prisoner Dilemma Game (PDG)

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1 Abstract

We are a non-profit company examining how lack of commitment can spread over a network. We investigated cascading failure behavior by modeling real-world socio-economic network systems playing the Prisoner's Dilemma Game (PDG), by replicating the experiments in a paper by Wang et al.

We verified the paper's analysis, concluding that (1) defection strategies for temporal high payoff can result in large, detrimental cascading failures or even the collapse of the entire network, and that (2) the optimal strategy for surviving catastrophic failures is cooperation.

Through this project, we show that short-term defection strategies can destabilize large networked systems, resulting in cascading failures. Moreover, we expect to demonstrate that a cooperative approach provides resilience against such failures, ensuring long-term network stability and reducing the risk of total system collapse.

2 Introduction

This final group project is for CSC324: Software Design and Development taught at Grinnell College in Fall 2024 by Dr. Fernanda Eliott. For this project, hypothetically we are a non-profit organization examining the effects of lack of commitment and its impact on cascading failures within real-world social and economic network systems. Specifically, we will investigate how defection and cooperation behaviors in a networked Prisoner's Dilemma Game (PDG) influence cascading failure behavior, potentially leading to large-scale network collapse. We observe this effect by changing the α value (the threshold to remove an agent from a network) and the β value (the incentive to defect) and analyzing its effects. By replicating a recent study by Wang et al., we aim to verify its findings and assess if defection strategies, while beneficial in the short term, contribute to system-wide vulnerabilities and lead to a cascading network failure.

3 Background Information

In this section, we provide context on our network system of agents.

3.1 Our Lattice

Our lattice (i.e. network system of agents) is initialized as below: each agent starts with four neighboring agents, and the red agent in the center of the lattice is the only defector. The rest of the agents, in blue, are cooperators.

In each iteration, all agents in the network interact, get removed from the network, and imitate.

3.2 Agent Interaction

In PDG, there are two players and they can choose either to cooperate or to defect. Both players are rewarded R for mutual cooperation, or a lower payoff (i.e. punishment) of P for mutual defection. In our analysis, R is set at 1 and P at 0. If one player decides to cooperate but the other defects, the

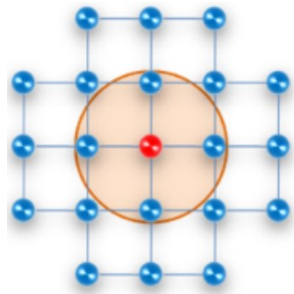

Figure 1: A visual representation of our lattice, taken from the paper by Wang et al.

defector gets the highest payoff T (the temptation to defect), while the cooperator receives the lowest payoff S. In our analysis, S is constant at 0. T is our variable, also known as β, which ranges from $1 < \beta < 2$. The payoff rank for PDG is, thus, $T > R > P > S$.

3.3 Agent Removal

Agent i will "die", or in other words, be removed from a network when:

$$P_i < T_i = \alpha_i P_i^N$$

Where:

1. P_i is the total payoff for agent i from all interactions with its neighbors
2. α_i is the threshold for an agent to survive (a variable)
3. P_i^N is the generic score when all agents decide to cooperate (which, in our case, is 4)

3.4 Agent Imitation

Agent i randomly selects an agent neighbor j with a probability $W_(i- > j)$, which is higher if the chosen neighbor is a defector because defectors will have a higher payoff.

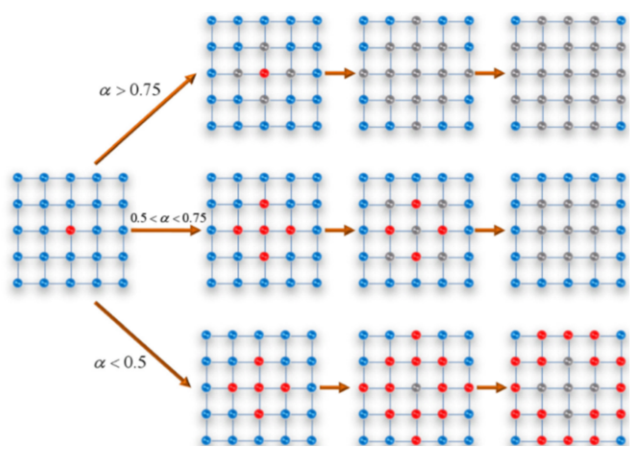

Figure 2: A visual representation of imitation and removal, taken from the paper by Wang et al.

4 Results

As our visualizations show, as expected, we arrived at the same results as the paper.

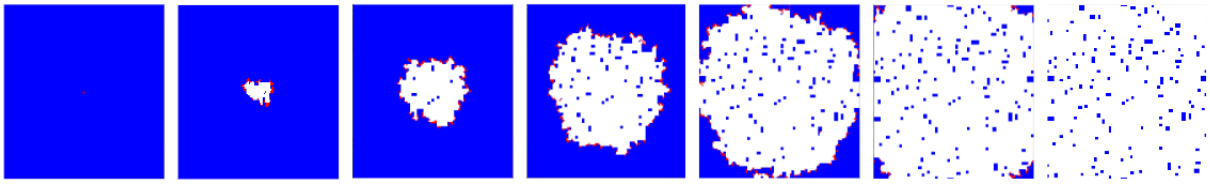

Figure 3: Visualizing our network through iterations for $\alpha = .49$, $\beta = 1.75$

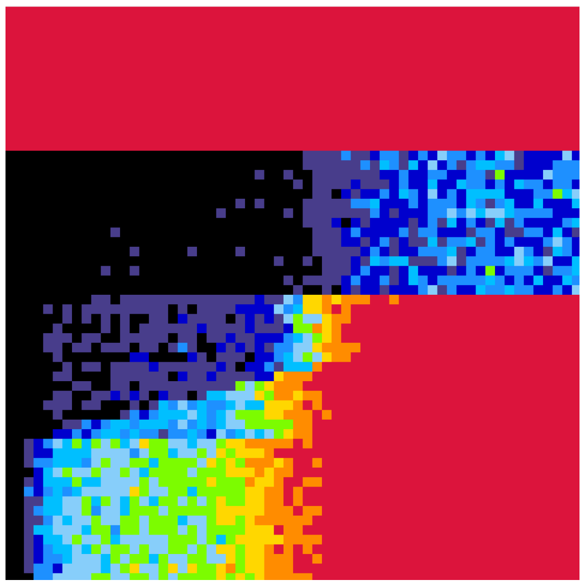

Figure 4: Comparing variables α and β, where $0 < \alpha < 1$ (y-axis) and $1 < \beta < 2$ (x-axis)

The red color in Figure 4 represents an "extinction" of all agents in the network, meaning that the total agent survival rate was below 10 percent. The black color, on the other hand, means that the total agent survival rate was above 90 percent. The colors in between represent a survival rate between 10 and 90 percent.

From these results, we can conclude that:

1. Defection for temporal high payoffs can trigger cascading failures or total network collapse.

2. Cooperation is the optimal strategy for surviving catastrophic failure scenarios.

5 Acknowledgements

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6 References

Wen-Xu Wang, Ying-Cheng Lai, Dieter Armbruster; Cascading failures and the emergence of cooperation in evolutionary-game based models of social and economical networks. Chaos 1 September 2011; 21 (3): 033112. https://doi.org/10.1063/1.3621719