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Final Analysis

Prisoner Dilemma Tournament

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1 Introduction

The Prisoner's Dilemma is a classic problem in game theory that shows how people might not work together, even when it would benefit them both. It's usually explained with a story: two people are caught by the police and questioned separately. They each have two choices — to stay silent (cooperate) or to confess (defect). If both stay silent, they get a light punishment. If one confesses and the other stays silent, the one who confesses goes free while the other gets a heavy sentence. But if both confess, they both get a moderate sentence.

This creates a problem: even though working together would lead to a better result, each person is afraid the other might betray them. So they often choose to confess (defect), which leads to a worse outcome for both. The Prisoner's Dilemma helps us understand why trust and cooperation are hard to achieve in competitive situations, and it has been used to study things like economics, politics, and even behavior in nature or between computer algorithms.

1.1 Simulation Setup

The tournament was full of interesting strategies for the Iterated Prisoner's Dilemma. The best ones found a smart balance between working together and choosing to betray when needed. In general, strategies that were more friendly and cooperative (called "Neat") ended up doing better than the more aggressive and unfriendly ones (called "Mean").

There were 60 people in total who took part, and 37 of them used Neat strategies. The competition had two rounds — the first one had 100 moves, and the second round unexpectedly lasted for 187 moves. The winning strategy, made by Sava Luchian and named Mahoraga, had an average score of 135.32, which was very high. It worked well because it mostly cooperated (around 87% of the time), but when the opponent started to defect, it smartly lowered its cooperation to about 34%. This shows that doing well in this game isn't just about always being nice or always betraying — it's about adapting to how the other player behaves.

2 Overall Performance Analysis

In the tournament, most strategies scored around the middle range, but a few did really well and got very high scores. This means the score results were not evenly spread—instead, they were skewed to the right. Most players had average results, but some strategies stood out and scored a lot more than the rest. For example, the top 10% of strategies had average scores over 15,000, while many others stayed around 13,000 to 14,000.

The top 10 strategies showed different smart ways of balancing cooperation and defection. Here are a few of the most successful ones:

1. **Mahoraga** – This strategy came in first place, with an average score of 15,968. It was based on a Tit-for-Tat style, meaning it copied what the opponent did last round. But what made it special was that it also included forgiveness—if the opponent made a mistake, Mahoraga could go back to cooperating after a while. This helped it avoid long fights and stay friendly when possible.

2. **One Liner** – This strategy also did really well, with a score of 15,905. It started by cooperating, but it kept a close eye on what the opponent was doing. If the opponent became aggressive, One Liner would change its behavior. This flexible approach helped it survive against both friendly and mean strategies.

3. **MaxRN** – With a score of 15,879, MaxRN played pure Tit-for-Tat. It simply repeated whatever move the opponent did last. This strategy works well because it's easy to understand and it creates a fair loop: if you cooperate, I cooperate. If you defect, I defect.

4. **Impermanent Retaliation** – This strategy scored 15,832. It was very cooperative when the opponent was too—it collaborated over 90% of the time if the opponent had collaborated last turn. But it also punished opponents when they defected, making it a balanced strategy that could fight back if needed.

5. **Shork** – Shork had a score of 15,794 and was another mostly cooperative strategy. Like Impermanent Retaliation, it would almost always cooperate if the opponent had done so. This shows that cooperation was a strong pattern among top strategies.

6. **Tea for Tat** – Scoring 15,790, this strategy was similar to Tit-for-Tat, but it had more patience. Even after being defected on, Tea for Tat would try to go back to working together instead of holding a grudge. That helped it recover quickly from small conflicts and continue building cooperation.

2.1 Visualization of Results

The graph from **Figure 1** shows the total scores from the first match, with algorithms ranked from best to worst. The top one hit nearly 16,000 points, while even the last place still got over 8,000. For the first 35 or so, the scores barely drop, meaning that it's a tight race. However, around ranks 40 to 50, the scores start to fall off more noticeably. Still, considering that no one completely flopped, it looks like most of the algorithms were pretty solid. Overall, the competition was strong and many well-designed strategies were clearly applied.

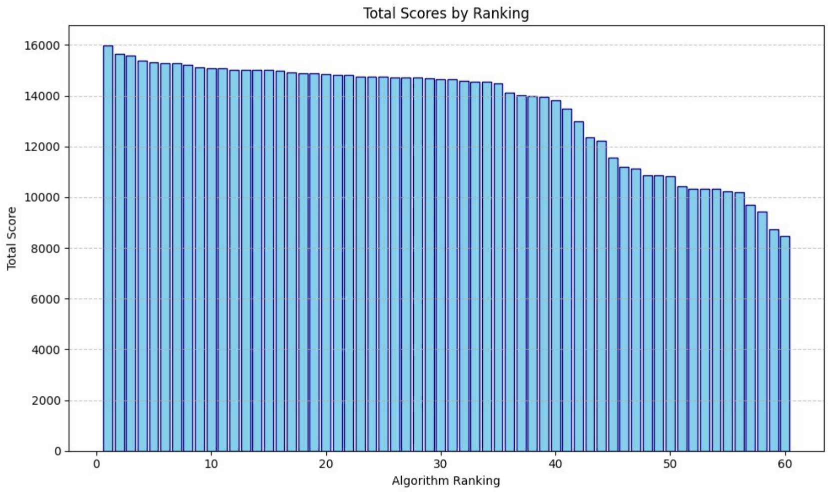

Figure 1: The distribution of total scores

The graph from **Figure 2** shows how likely each algorithm is to cooperate right after their opponent also cooperated. The x-axis shows the algorithm's ranking (from 1 to 60), and the y-axis shows the probability of it cooperating after seeing the opponent do the same.

We can see that the higher-ranked algorithms (on the left side) tend to cooperate a lot after the opponent collaborates—many of them have probabilities close to 100%. That means these top algorithms are rewarding cooperation, which is often a good long-term strategy in the Prisoner's Dilemma. They build trust and likely end up scoring well by avoiding mutual defections. On the other hand, some lower-ranked strategies (right side) are a bit more inconsistent. Their cooperation rates are up and down, showing less stable behavior. This suggests they might be less predictable or more "noisy," which could explain their lower performance.

This graph supports the idea that forgiveness and positive reinforcement (like co-operating again when the opponent cooperates) is an effective and common trait among top-performing strategies. It helps create long-term collaboration loops and avoids unnecessary conflict.

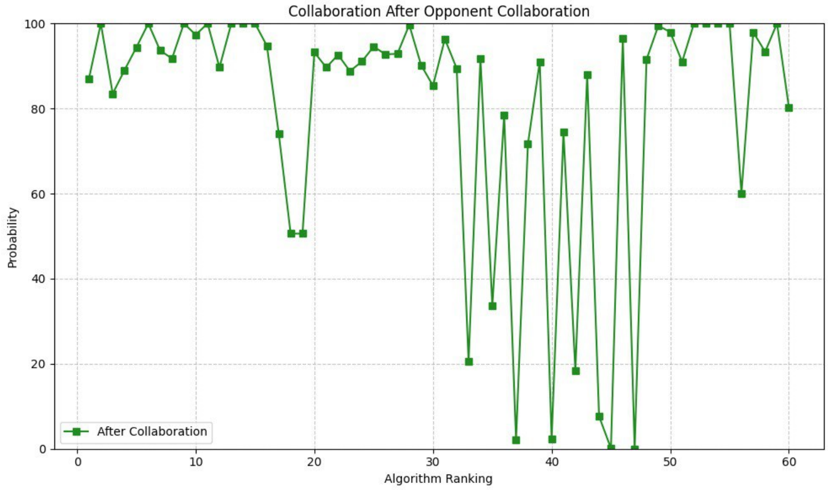

Figure 2: The probability to cooperate given on the last round

The graph from **Figure 3** shows how likely algorithms are to cooperate after their opponent defects. It uses the same setup: algorithm ranking on the x-axis, and cooperation probability on the y-axis.

Here, there's a clear difference compared to the first graph. The top-ranked algorithms (on the left) almost never cooperate after being betrayed—many sit around 0% cooperation. This tells us that successful algorithms are tough and retaliate when someone defects, which makes sense. In the Iterated Prisoner's Dilemma, being too forgiving can lead to being taken advantage of. These high-ranked algorithms probably use strategies like "Tit for Tat" or "Grim Trigger," which punish defections to discourage betrayal.

However, when we look to the lower-ranked strategies (right side), there are some that actually continue to cooperate even after being betrayed. That might make them seem "nicer," but in this competitive tournament setting, it probably made them easier targets, explaining why they ended up ranked lower. These strategies might not punish enough, so opponents keep defecting and gaining more points.

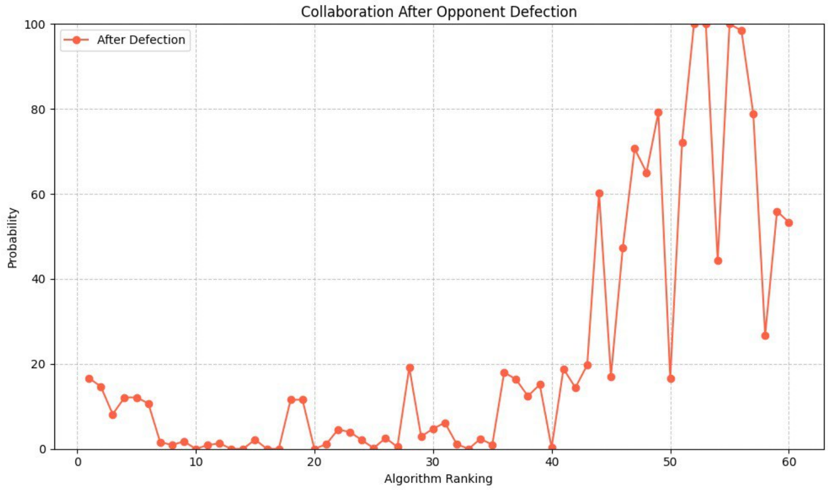

Figure 3: The probability to cooperate given on the last round

The graph displayed in **Figure 4** version compares how many times defection and collaboration have been used. Going untill the 45th rank, it is clearly observed that all the strategies defected more than cooperated, which is aroun 30%, reaching its spike to 50%. As we move to bigger ranking, cooperation is mostly used rather than defection, here clearly defection having a maximum rate of 30%. This reflects the fact that the algorithms that most of the time just cooperate, without any well-thought strategy are more likely to lose. This graph reaffirms that maintaining cooperation is key. Still, there is place for defection, because only cooperation will lead to loss. In competitive environments, the best performers are those who build trust-based loops rather than trying to squeeze out extra points by defecting opportunistically. Yet, the climb is not perfectly linear, suggesting that successful strategies aren't naïve. There's still some experimentation and conditionality — perhaps "Tit-for-Tat"-like behaviors where initial cooperation is contingent on the opponent's behavior. But ultimately, mutual cooperation dominates the elite cluster, showing that successful strategies learned to build and sustain trust.

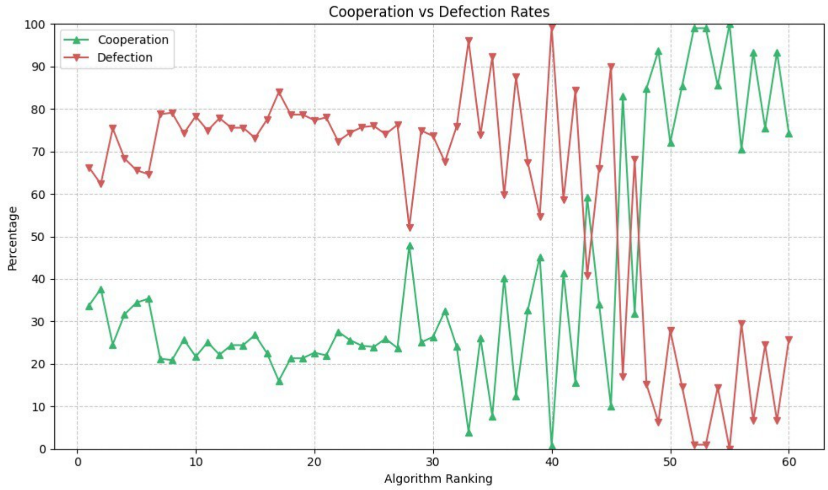

Figure 4: The percentage of defection and collaboration

2.2 Behavioral Analysis

Analyzing the behavior of top and bottom performers reveals key insights into successful strategies within the Iterated Prisoner's Dilemma tournament.

The ten highest-ranking strategies shared a common foundation: conditional cooperation. They exhibited an average cooperation rate of 93.4% after the opponent cooperated, and just 7.86% after the opponent defected. This demonstrates not blind trust, but responsive and strategic collaboration—rewarding goodwill while punishing betrayal.

Interestingly, only 2 of the top-performing strategies were labeled "Mean". The rest belonged to the "Neat" or mixed categories. Most "Mean" strategies were clustered much lower in the rankings, around 45th to 60th place, indicating that persistent harshness or rigidity tends to underperform. Meanwhile, only three "Neat" strategies landed in the bottom tier (46th, 53rd, and 59th), showing that cooperation alone isn't enough—it must be adaptive and context-aware.

At the other end, the worst-performing strategies tended to exhibit extreme behaviors—either overly cooperative or overly rigid.

A good example is the strategy ISSA Knife, which chose to cooperate 99% of the time, no matter how the opponent acted. Because it always tried to be friendly, even when others weren't, it ended up with a very low score. This shows that being too nice without protecting yourself can be a big weakness in the Prisoner's Dilemma. In this kind of game, you need to know when to defend yourself—always cooperating isn't a smart strategy if others can easily take advantage of you.

A surprising result came from the strategy "Pavlov with forgiveness" by Artur Tugui. Even though it never cooperated after being betrayed, it still managed to rank 10th overall. This shows that being strict and firm can work well, as long as the strategy is also smart and flexible in other parts. Its success proves that a clear and consistent reaction to opponents—even if it's strict—can be better than strategies that either forgive too easily or never forgive at all.

There seems to be a "perfect zone" for how much a strategy should cooperate. Most of the top strategies cooperated between 85% and 95% of the time. These strategies found a good balance—they were friendly enough to build cooperation but also punished opponents who betrayed them, so they wouldn't be used or tricked.

Most of the best strategies were very cooperative, but only when the opponent was too. On average, they cooperated more than 85% of the time after the opponent also cooperated. However, when the opponent defected (betrayed them), they became less friendly and only cooperated between 25% and 40% of the time.

This difference in behavior is called a response gap ($\triangle P$), which shows how much the strategy changes its actions depending on the opponent. A large gap means the strategy knows how to punish bad behavior but can still go back to being nice if things improve. For example, a strategy might work like this:

1. P(Cooperate | Opponent Cooperated) = 0.95
2. P(Cooperate | Opponent Defected) = 0.34
3. $\triangle P = 0.61$

This big gap ($\triangle P = 0.61$) helps the strategy stay kind but also careful not to get fooled.

This kind of responsive drop punishes the opponent but does not permanently sever the possibility of mutual benefit.

Importantly, top strategies were not purely retaliatory. They maintained an average 34% cooperation rate after an opponent's defection, introducing an element of forgiveness. This trait allows cooperation to recover after momentary betrayals, avoiding long-term breakdowns from short-term mistakes. One particularly effective model was a modified Tit-for-Tat, which defected once in retaliation but returned to cooperation if the opponent did the same. This kind of measured retribution with a path to reconciliation emerged as the dominant behavioral pattern among successful strategies.

2.3 How the Type of Strategy Affected Results

From the top 30 strategies in the rankings, 22 of them (about 73.3%) were Neat strategies, while only 8 (about 26.7%) were Mean. This shows that being cooperative most of the time was a more successful approach overall.

The average score for Neat strategies was around 15,553, showing that they performed very well across both matches. Most of them followed patterns like Tit-for-Tat, or had high base cooperation but with smart retaliation if the opponent defected. These strategies were good at building trust with their opponents while still defending themselves when needed. Because they stayed calm and consistent, they avoided long punishment cycles and earned high scores.

On the other hand, the Mean strategies averaged a slightly lower score of about 15,315. Although fewer of them made it to the top, they still showed that aggression could work—but only if used carefully. The successful Mean strategies didn't just defect blindly. Instead, they mixed in cooperation to stay unpredictable, or they tested opponents first to find out how much they could get away with. If they defected too often without adapting, they ended up at the bottom of the rankings. So, balance and flexibility were still key to success, even for the more aggressive players.

In short, while both styles could succeed, cooperative strategies had a clear edge, especially when they combined kindness with a bit of caution.

2.4 Case Studies

To fully understand the dynamics of success and failure in this iterated simulation, we analyze specific strategies that represent both the upper and lower bounds of performance. This section evaluates their behavioral patterns, explores the underlying mechanics of their results, and draws broader insights about what defines effective game-theoretic behavior.

As stated above, Mahoraga, the top-performing strategy, achieved an outstanding average score of 135.32 across 72 rounds. It maintained a cooperation rate of 87.06% after an opponent's cooperation, and only 16.67% after an opponent's defection. This places it squarely in the "Neat" classification, but with a more complex behavioral profile than a naïve cooperator.

Mahoraga exemplified conditional cooperation with targeted, strategic retaliation. Its low post-defection cooperation rate signals a punishment system, yet the 16.67% is not zero—suggesting forgiveness and recovery, not rigid vendetta. Furthermore, its 59.32%

win rate reflects the ability to outperform opponents while still maintaining cooperative relationships where possible. This strategy avoided destructive defection loops and showed an ability to repair trust, making it a prime example of effective behavioral balance in iterated games. It confirms that moderate defection, combined with a strong cooperative core, leads to dominant performance.

The second-place strategy, One Liner by Islam AbuKoush, was built around a very cooperative idea. It always cooperated (100%) after the opponent cooperated, and still cooperated 14.66% of the time even after the opponent defected. At first, this might seem too kind or even weak—but the strategy actually performed very well, earning 132.69 points and finishing in second place overall.

That said, One Liner wasn't completely soft. A closer look shows it still cooperated about 62.34% of the time after the opponent defected, meaning it did punish bad behavior sometimes, just not very harshly. This kind of strategy works well when most other players are also being nice. But in a more competitive or aggressive environment, it could easily be taken advantage of. Its success in this tournament shows how important the overall mood of the game is—One Liner fit in well with the mostly cooperative atmosphere, but it might struggle if most opponents were more hostile.

Maxim Roenco's strategy "MaxRN", ranked third with 131.91 points, was labeled "Mean", but its behavior suggests a more nuanced profile. It cooperated 83% of the time following cooperation, but only 8.16% after a defection, indicating a strict retaliation policy.

While classified as "Mean", this binary behavior—cooperate if treated well, punish harshly if not—resembles classic Grim Trigger or strong Tit-for-Tat logic. This case challenges the simplicity of "Neat vs. Mean" labels and emphasizes that sharp retaliation doesn't always equate to meanness, especially if the strategy is otherwise cooperative. MaxRN succeeded by enforcing discipline, not chaos.

What regards the strategy classifed on the 6th place called "impermanent retaliation", it is well observed that it is based on high conditional cooperation. It cooperates 94.4% after an opponent cooperates and only 12.1% after a defection. With a 34.4% overall cooperation rate and 65.6% defection rate, it balances. Its 57.6% win rate and average of 129.86 points per matchup confirm how effective is the strategy which rewards cooperation. However, in overly cooperative environments, its high defection rate could limit its gains.

At the other end of the spectrum, Cosmin Usurelu's "ISSA Knife" maintained an extremely high cooperation rate (99%), essentially refusing to defect under any circumstance. Despite its unwavering friendliness, it ranked among the lowest scorers, with an average around 87 points.

This result demonstrates a core truth of iterated game theory: unconditional cooperation is exploitable. ISSA Knife likely fell into repetitive 1-point outcomes against defectors, offering high payoffs to opponents and receiving the minimum. Even when paired with other cooperators, it failed to capitalize on opportunities to earn more, because it never adjusted its behavior. This confirms that blind friendliness is not a viable long-term strategy in competitive or mixed-behavior populations.

The interesting part is that the participant with the fewest points uses a neat strategy called "Astrologer". There is a high overall cooperation rate of 74.24%, including 80.3% cooperation after the opponent cooperated and an unexpectedly high 53.34% even after the opponent defected. This neat strategy wins 61% of the rounds, reflecting its advantage. However, the low score and high tolerance for defection imply that the strategy is much more based on trust, which could be the reason for not being in the higher ranks. It is a classic case of a cooperative agent that survives, but doesn't prosper in a mixed-behavior ecosystem.

Another capturing case is the strategy that hit the 20th place: "Gambler". It earned a total score of 14895, and achieving 72 almost perfec rounds. It exhibited low cooperation: only 11.57% after an opponent's defection and just 50.6% after cooperation. With an overall cooperation rate of 21.32% and defection rate nearing 79%, this strategy relied heavily on persistent defection. Despite this aggression, it managed a surprisingly balanced outcome: 42.37% wins, 49.15% draws, and only 8.47% losses. There can be easily observed the fact that this algorithm expected the opponents to have a neat strategy, therefore being more prone to cooperating rather than just defecting.

2.5 Key Insights and Lessons Learned

This tournament provided important lessons about how strategies work in the Iterated Prisoner's Dilemma. One of the key takeaways is that a balanced approach tends to work best. The best strategies didn't just cooperate all the time or act aggressively all the time. Instead, they adjusted their behavior based on the actions of their opponents. If the opponent was cooperative, these strategies would respond by continuing to cooperate. However, if the opponent chose to defect, the successful strategies would punish the defection, but they wouldn't completely shut down cooperation. They understood that cooperation could be restored after a defection, which helped them maintain stronger relationships and higher scores in the long run.

Another important lesson is that extremes—whether it's too much cooperation or too much aggression—rarely lead to success. Some strategies, like ISSA Knife, cooperated 99% of the time, regardless of how their opponent behaved. These strategies were quickly exploited by opponents who defected often, and as a result, they performed poorly. On the other hand, strategies that were too aggressive, with little or no willingness to cooperate after a defection, also failed to achieve high scores. This showed that flexibility and the ability to adapt to the behavior of others is essential for long-term success.

In addition, we learned that cooperation alone is not enough. A strategy that cooperates without being ready to defend itself or adjust when needed is vulnerable to exploitation. However, being too strict and never allowing for forgiveness can also lead to poor performance. The most successful strategies were able to mix cooperation with strategic retaliation, knowing when to forgive and when to punish. This allowed them to avoid constant conflict while still protecting themselves from being taken advantage of.

3 Conclusion

In conclusion, the tournament offered valuable insights into the nature of cooperation, defection, and retaliation in repeated games. The key to success in the Iterated Prisoner's Dilemma is not about choosing one strategy over another, but about adapting to the behavior of your opponent. Strategies that were too cooperative or too aggressive failed because they did not adjust their behavior when needed. The top strategies were able to maintain cooperation while also knowing when to defend themselves through retaliation. This balance of cooperation and strategic punishment was the secret to their success.

Moreover, the tournament revealed the importance of the environment in which strategies are applied. If most players are cooperative, strategies that emphasize cooperation are likely to perform well. However, in a more competitive or aggressive environment, strategies that are too cooperative may struggle to survive. This suggests that understanding the behavior of your opponents and being able to adjust your strategy accordingly is just as important as the strategy itself. The best strategies were those that remained flexible and responsive, taking into account both their own behavior and that of their opponents.

Ultimately, the tournament emphasized that success in the Iterated Prisoner's Dilemma is about finding the right balance. Strategies that cooperated at the right times, but were willing to retaliate when necessary, consistently performed the best. The ability to forgive while also protecting oneself from exploitation allowed these strategies to thrive and secure top spots. This shows that in game theory, as in life, the most successful players are those who know how to adapt, learn from others, and find a path to cooperation without losing sight of their own needs.