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BSc Thesis

Possible effects of lost, wrong and delayed information on the evolution of cooperation

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Abstract

This paper investigates possible effects of different information deficiencies on the evolution of cooperation on the basis of the Iterative Prisoner's Dilemma. To this end, an evolving pool of players repeatedly participates in Round-Robin tournaments. The effect of 5% lost, 5% wrong and 5% delayed information on the amount of games in which both players cooperate per generation, the average payoff received by players per generation and the total age of the player pool is examined. The method used to research the different information deficiencies is discussed extensively and suggestions for further research are given. The conducted research makes it apparent how information deficiencies can decrease the amount of games in which both players cooperate, the average payoff and how it can increase the total age of all players in the pool per generation. At the same time, it is observed how cooperative behavior is still present in all of the performed experiments.

1 Introduction

The existence of cooperative behavior has played a key part in the development of human society. The development of cooperative behavior and the impact that different environmental factors have on the evolution of cooperation have been studied in a number of ways. One model on the basis of which the evolution of cooperation can be studied is the Iterative Prisoner's Dilemma (IPD).

This paper focuses on the effect of lost, wrong and delayed information on the evolution of cooperation for the Iterative Prisoner's Dilemma. It aims to support further research with regards information deficiencies in the evolutionary Prisoner's Dilemma by researching possible effects of lost, wrong and delayed information and by showing a possible method in which such effects could be investigated.

The most basic form of the Prisoner's Dilemma (PD) is a simple two-player game in which both players have the choice to either cooperate or defect. The payoff for either player, given both their own choice and the choice of their opponent, is illustrated by the following table:

Player1/Player2	Cooperate	Defect
Cooperate	R/R	S/T
Defect	T/S	P/P

The following relationships must hold for the variables in the payoff matrix[CY05]:

1. T > R and P > S (each individual player receives more if they defect)
2. R > P (mutual cooperation is more rewarding than mutual defection)
3. 2R > (T + S) (alternating between exploiting the other player and getting exploited by the opponent realizes less payoff than mutual cooperation)

The Iterative Prisoner's Dilemma (IPD) has two players play PD against each other repeatedly. If players have memory, they can use information on previous rounds to decide whether they will cooperate or defect in the next round. This is the foundation of player strategies.

1.1 Simulation idea

This paper explores the evolution of cooperation by means of a variant of the Iterated Prisoner's Dilemma. First, a pool of players is constructed with random strategy representations. These players then participate in a Round-Robin tournament. This means each player plays a game of IPD against each other player in the pool. After the Round-Robin tournament, the players which have collected the lowest amounts of payoff are removed from the pool. The most successful players are allowed to reproduce. The new players are added to the pool, essentially replacing the removed players. The new pool of players participates in the next Round-Robin tournament. This process is repeated over a number of iterations.

Investigating the evolution of cooperation by means of repeated Round-Robin tournaments has been done before by Nicky Case[Cas17] as well as Siang Y. Chong and Xin Yao[CY05]. More details on the used model will be discussed in section 2.

1.2 Research questions

This paper aims to investigate players with memory length 1, 2 and 3 and the effects of either 0% or 5% lost, wrong and/or delayed information. As will be clarified in the next section, this research is not exhaustive with regards to these parameters. Taking all of this into account, the following research question and subquestions have been formulated:

> What are some of the possible effects of 5% lost, wrong and/or delayed information on the evolution of cooperation for the Iterated Prisoner's Dilemma with player memory size 1, 2 and 3?
>
> – What are some of the possible effects of 5% lost, wrong and delayed information on the number of PD games in which both players decide to cooperate?
> – What are some of the possible effects of 5% lost, wrong and/or delayed information on the highest, average and lowest payoff receives by players over the iterations?
> – What are some of the possible effects of 5% lost, wrong and delayed information on the development of total age of players over the iterations?

In the end, the performed exploratory research resulted in possible effects of lost, wrong and delayed information deficiencies on the aspects mentioned in the subquestions. In addition, suggestions are provided with regards to how the effects on these information deficiencies can be researched further.

1.3 Outline of the paper

The remainder of this section will examine other papers with interesting research relating to the work done in this paper. Section 2 will elaborate on the specifics regarding the model used for investigation as well as discuss the limitations to the research that has been done. Section 3 concerns how different attributes of the evolution of cooperation were investigated and analyzed. Section 4 is a comprehensive overview of the different observations made from the analysis of our experiments. Section 5 summarizes the observed effects of the information deficiencies in our experiments and provides ideas with regards to future directions of research.

1.4 Related research

This subsection aims to examine papers which research is closely linked to the research done in this paper. The aim is to find material which is able to assist in the analysis of the observations.

Chong and Yao have conducted extensive empirical research with regards to the effects of wrong information on the evolution of cooperation[CY05]. One of the ways in which they represented player strategies was by means of lookup tables. This representation is the foundation for the representation that will be used in this paper. They have found that the development of cooperation in this model is resistant to low amounts of wrong information ($\leq 1.5\%$). Additionally, they observed that , when using this strategy representation, very high levels of wrong information could lead to cyclic behaviors over the generations, which refers to the alternating dominance of cooperation and defection. They conclude that high amounts of wrong information decrease levels of cooperation and create misunderstandings.

Lindgren states that the presence of noise allows for increased length of transients in their evolutionary model[Lin91]. This suggests information deficiencies can have effects on the evolution of cooperation.

Kurokawa has performed elaborate research on the effects of different information deficiencies - including both wrong information and lost information - on the evolution of cooperation[Kur17]. They investigated the evolutionary stability of certain strategies with regard to others. In contrast, this paper aims to observe the general evolution of cooperation for mutating strategies, starting with a random pool.

The effect of memory size on the evolution of cooperation is relevant to this paper due to the fact that bigger memory sizes allow for the study of information with longer delays. Kretz has investigated the effect of memory size on the performance of strategies in RR-tournaments[Kre11]. However, their investigation did not include an evolutionary aspect or information deficiencies. This means their conclusions on the effect of memory do not appear relevant to the research done in this paper.

Hauert and Schuster also investigated the effect of memory size on the evolution of cooperation[HS97]. However, their strategies representation allow for conditional probabilities and delayed information is not explored either. This prevents this paper from adopting their conclusions with regards to the influence of memory size.

Press and Dyson have shown that in a two player game of IPD where an identical game is repeated, increased memory size does not give players an advantage[PD12]. However it is unclear whether this is still the case when longer memory means a larger amount of possible moves a player can register, as is the case in this paper.

2 Methodology

The general idea on what is simulated has already been provided in the previous section. This section deals with the specifics of the used model.

2.1 Chosen parameters

A number of the parameters align to [CY05]. The number of iterations in one game of IPD is 150, which allows for comparisons to their work. T, R, P & S take on values 5, 4, 1 & 0 respectively.

The evolution of cooperation is observed for 600 iterations per experiment and each experiment is simulated 30 times. The size of the player pool is 30. These numbers are of sufficient size in that they allow for interesting observations regarding the effect of lost, wrong and delayed information (LWD information).

The performed research is restricted by the parameters in the setting. As discussed in the previous section, different rates of wrong information have led to different observations in research performed by Siang Y. Chong and Xin Yao. This paper does not aim to be an exhaustive investigation of lost, wrong and delayed information. Empirical research to this extent is simply not possible given the number of variations there can be to the payoff matrix, size of the player pool, number of rounds per game of IPD, mutation frequency, player strategy representation and what games each player plays in an iteration.

2.2 Modeling of player strategies & lost, wrong and delayed information

During a game of PD, players are aware of both their own actions and their opponents' actions for the past n games of PD, where $n = 1, 2, 3$ is the memory size of the players. The strategy a player employs is represented by a lookup table. For each combinations of actions they will they either cooperate or defect.

Players always remember their own actions correctly. This means the number of different possible combinations of actions they can remember having performed themselves is

$$S_n = \sum_{i=0}^{n} 2^i$$

where n is the memory length.

Players cannot always remember their opponents' actions correctly. Information about their opponents might be lost, wrong or delayed.

Players do not know whether information they receive is wrong. When there is 5% wrong information, the game will have 5% chance to tell a player their opponent cooperated or defected during a certain round, while the opposite is true.

Players are able to observe their absence of information regarding the move of an opponent. They do not know whether they are dealing with lost information or delayed information that will still arrive. When delayed information arrives, players know that it had been delayed, which increases the number of different combinations of knowledge they can have regarding the moves played by an opponent.

If purely looking at all of the different actions a player can register their opponent having performed, and combining those options over a number of rounds, the number of different possible combinations of actions a player can remember their opponent having performed is

$$T_n = \sum_{i=0}^{n} (2n+1)^i$$

where n is the memory length. This number is used to build the lookup table representation.

The formulas presented so far demonstrate that the size of a lookup table representing a strategy is dependent on the memory size of the player that employs it. The number of entries is a lookup table is

$$L_n = S_n * T_n = \sum_{i=0}^{n} \sum_{j=0}^{n} (2)^i * (2n+1)^j$$

where n is the memory length. The lookup table contains a number of illegal entries, for which the delay on a registered move performed by an opponent is greater than the time between now and when the PD game was played.

2.3 The mutation algorithm

The mutation algorithm allows a player to produce a child employing a slightly different strategy as their parent. A number of entries in their lookup table are changed from either cooperate to defect or from defect to cooperate.

In the performed experiments, a player always remembers as many of their own past decisions as they do decisions made by the opponent. This means entries in lookup table for which $i \neq j$ in the formula above will not influence the decisions made by each player. However, the remaining entries still include the illegal memory configurations previously mentioned.

In order to compensate for the increasing percentage of entries for which $i \neq j$ when memory size grows to 3, the mutation algorithm allows more changes to a lookup table.

For memory size 1, the mutation algorithm will change one out of twelve entries. The chance of affected entry being relevant to the strategy employed by the player is 7/12.

For players with large memory sizes, the number of entries changed is

$$C_n = \lfloor L_n * (1/12) * ((7/12)^{-1} / (K_n/L_n)^{-1})^{-1} \rfloor$$

where K_n is the number of entries for which $i = j$.

2.4 Player pool dynamics

The size of the player pool remains constant throughout each experiment. After each iteration, the 15 players which have collected the least amount of payoff are removed from the pool. The other 15 players each produce a child using the mutation algorithm discussed above.

3 Analysis

The previous sections explained the details with regards to the model used to test the effect of different information deficiencies on the evolution of cooperation. This section discusses exactly what experiments have been carried out. It states what initial observations have been made from the recorded data and which statistical tests have been performed as a result of them.

3.1 Performed experiments

From here on out, an experiment refers to the 30 simulations of a repeated Round-Robin tournament. A number of experiments have been performed to answer the research questions. Table 1 shows what experiments have been performed as well as how they differ from each other in terms of parameters.

Experiment no.	Memory size	Lost%	Wrong%	delayed %
1	1	0	0	N/A
2	1	0	5	N/A
3	1	5	0	N/A
4	1	5	5	N/A
5	2	0	0	0
6	2	0	0	5
7	2	0	5	0
8	2	0	5	5
9	2	5	0	0
10	2	5	0	5
11	2	5	5	0
12	2	5	5	5
13	3	0	0	0
14	3	0	0	5
15	3	0	5	0
16	3	0	5	5
17	3	5	0	0
18	3	5	0	5
19	3	5	5	0
20	3	5	5	5

Table 1: Performed experiments and their differing parameters.

A number of attributes have been recorded for each experiment. Graphs have been created from the resulting data and initial observations from these graphs have led to a number of statistical tests.

Appendix A contains graphs on a number of attributes that will be examined closely in the remainder of this section:

- The amount of PD games in which both players cooperate per generation.
- The average payoff received by the players participating in a generation, per generation.
- The total amount of IPD games played by all players after each generation.

The data points in these graphs are merely the means of the 30 experiments for the above metric.

3.2 The amount of PD games in which both players cooperate

The graphs in Appendix A suggest the possibility that an experiment with 5% wrong information decreases the average amount of PD games in which both players cooperate per generation, when compared to the equivalent experiment without 5% wrong information.

In order to measure that one experiment has a statistically significant lower mean number of games in which both players cooperate per generation when compared to another experiment, a one-tail two-sample t-test for the mean accounting for unequal variance has been performed on each generation, with a significance level of 5%.

These statistical tests have been performed for each 5% information deficiency, to test whether their presence decreases the amount of games in which both players cooperate. Table 2 displays the results of the statistical tests.

The labels above of each of the columns have the following meaning: **No. lower** and **No. higher** refer to the experiments for which the statistical test(s) (per generation unless specified) is/are performed. The statistical tests are performed in order to examine whether the mean value of the attribute in the first experiment is statistically significantly lower when compared to the second experiment. **MS** refers to the memory size of both experiments being compared. **Both** refers to 5% information deficiencies present in both experiments. **One** refers to the 5% information deficiency of which the presence in one experiment might lead to a statistically significant difference between that experiment and the experiment it is being compared to. **Expected** refers to whether, prior to the analysis, statistical significance was expected based on the graphs in Appendix A. **Concluded** refers to whether statistical significance seems present given the performed statistical test(s). **Counted** is the number of generations for which the alternative hypothesis is accepted on the basis of the statistical tests performed. **Total** is the maximal number of generations for which the statistical test accepts the alternative hypothesis (the first two iterations are always identical when it comes to total pool age). **Last fail** refers to the last generation for which the statistical test failed to reject the null hypothesis, if that generation exists.

One issue pertains to when to conclude that the presence of certain information deficiencies in one experiment do indeed lower the number of an attribute when compared to the identical experiment in which these deficiencies are absent. In the case that statistical tests are performed for each generation, must statistical significance be observed in all iterations? This paper has chosen to conclude a difference if $count \geq 580$. It also aims to to distinguish those cases for which $count = 600$ (or 598 in the case of total pool age) from the other results. In the **Concluded** column of the tables, Y refers to statistical significance concluded for all generations (or in general if only one statistical test is needed to compare metrics). Y_q refers to cases for which a difference is concluded, but statistical significance is not observed for each generation. N and N_q refers to cases in which no difference is concluded.

No. lower	No. higher	MS	Both	One	Expected	Concluded	Count	Total	Last fail
2	1	1	...	W	Y	Y	600	600	...
3	1	1	...	L	N	N_q	521	600	599
4	2	1	W	L	N	Y_a	596	600	592
4	3	1	L	W	Y	Y	600	600	...
6	5	2	...	D	N	N	277	600	597
7	5	2	...	W	Y	Y	600	600	...
9	5	2	...	L	N	N	294	600	600
8	6	2	D	W	Y	Y	600	600	...
10	6	2	D	L	N	Y	600	600	...
8	7	2	W	D	N	N	218	600	563
11	7	2	W	L	N	N	354	600	583
10	9	2	L	D	N	Y_a	599	600	96
11	9	2	L	W	Y	Y	600	600	...
12	8	2	W, D	L	N	Y_a	587	600	571
12	10	2	L, D	W	Y	Y	600	600	...
12	11	2	L, W	D	N	N_q	529	600	579
14	13	3	...	D	N	N_q	572	600	539

15	13	3	...	W	Y	Y_a	599	600	121
17	13	3	...	L	N	N_q	558	600	577
16	14	3	D	W	Y	Y	600	600	...
18	14	3	D	L	N	Y	600	600	...
16	15	3	W	D	N	Y	600	600	...
19	15	3	W	L	N	Y	600	600	...
18	17	3	L	D	N	Y	600	600	...
19	17	3	L	W	Y	Y	600	600	...
20	16	3	W, D	L	N	Y	600	600	...
20	18	3	L, D	W	Y	Y	600	600	...
20	19	3	L, W	D	N	Y	600	600	...

Table 2: Results of the statistical tests on the average amount of games in which both player cooperate per generation.

3.3 The average payoff received by players

The graphs in Appendix A suggest the possibility that the presence of 5% wrong information decreases the average payoff received by a player in each generation.

In order to measure that one experiment has a statistically significant lower mean average payoff received by players per generation when compared to another experiment, a one-tail two-sample t-test for the mean accounting for unequal variance has been performed on each generation, with a significance level of 5%.

These statistical tests have been performed for each information deficiency, to test whether their presence leads to a decrease in the average payoff received by a player in each generation. The results of these tests are found in Table 3.

No. lower	No. higher	MS	Both	One	Expected	Concluded	Count	Total	Last fail
2	1	1	...	W	Y	Y	600	600	...
3	1	1	...	L	N	Y_a	584	600	562
4	2	1	W	L	N	Y_a	596	600	592
4	3	1	L	W	Y	Y	600	600	...
6	5	2	...	D	N	N	241	600	597
7	5	2	...	W	Y	Y	600	600	...
9	5	2	...	L	N	N	264	600	600
8	6	2	D	W	Y	Y	600	600	...
10	6	2	D	L	N	Y_a	599	600	98
8	7	2	W	D	N	N	169	600	600
11	7	2	W	L	N	N	253	600	600
10	9	2	L	D	N	Y_a	597	600	584
11	9	2	L	W	Y	Y	600	600	...
12	8	2	W, D	L	N	Y_a	584	600	571
12	10	2	L, D	W	Y	Y	600	600	...
12	11	2	L, W	D	N	N	500	600	600
14	13	3	...	D	N	N_q	563	600	539
15	13	3	...	W	Y	Y_a	595	600	122
17	13	3	...	L	N	N_q	522	600	577
16	14	3	D	W	Y	Y	600	600	...
18	14	3	D	L	N	Y	600	600	...
16	15	3	W	D	N	Y_a	598	600	568
19	15	3	W	L	N	Y	600	600	...
18	17	3	L	D	N	Y	600	600	...
19	17	3	L	W	Y	Y	600	600	...

20	16	3	W, D	L	*N*	*Y*	600	600	...
20	18	3	L, D	W	*Y*	*Y*	600	600	...
20	19	3	L, W	D	*N*	*Y*	600	600	...

Table 3: Results of the statistical tests on the average average payoff received by players per generation.

3.4 On the moving average

The graphs in Appendix A suggest the possibility that the presence of any 5% information deficiency slows down the rate at which the simple moving average (19 values, 9 on either side of the central value, generations for which there are not enough values on one side are not considered) of the number of PD games in which both players cooperate decreases after having increased first.

Only one statistical test needs to be performed in order to compare two experiment with regards to this attribute (not for each generation). In order to measure that one experiment consistently requires less iterations for the mentioned point to be reached when compared to another experiment, a one-tail two-sample t-test for the mean accounting for unequal variance has been performed, with a significance level of 5%.

These statistical tests have been performed for each information deficiency, to test whether their absence decreases the the mean number of iterations it takes for the simple moving average to reach the mentioned point. The results of the statistical tests are displayed in Table 4. The last three columns present in the other tables are not necessary here, since only one statistical test is performed for each comparison between two experiments.

No. lower	No. higher	MS	Both	One	Expected	Concluded
1	2	1	...	W	*Y*	*Y*
1	3	1	...	L	*Y*	*Y*
2	4	1	W	L	*Y*	*Y*
3	4	1	L	W	*Y*	*Y*
5	6	2	...	D	*Y*	*Y*
5	7	2	...	W	*Y*	*Y*
5	9	2	...	L	*Y*	*Y*
6	8	2	D	W	*Y*	*Y*
6	10	2	D	L	*Y*	*Y*
7	8	2	W	D	*Y*	*Y*
7	11	2	W	L	*Y*	*Y*
9	10	2	L	D	*Y*	*Y*
9	11	2	L	W	*Y*	*Y*
8	12	2	W, D	L	*Y*	*Y*
10	12	2	L, D	W	*Y*	*Y*
11	12	2	L, W	D	*Y*	*Y*
13	14	3	...	D	*Y*	*Y*
13	15	3	...	W	*Y*	*Y*
13	17	3	...	L	*Y*	*Y*
14	16	3	D	W	*Y*	*Y*
14	18	3	D	L	*Y*	*Y*
15	16	3	W	D	*Y*	*Y*
15	19	3	W	L	*Y*	*Y*
17	18	3	L	D	*Y*	*Y*
17	19	3	L	W	*Y*	*Y*

16	20	3	W, D	L	Y	Y
18	20	3	L, D	W	Y	Y
19	20	3	L, W	D	Y	Y

Table 4: Results of the statistical tests on the average amount of rounds it takes for the simple moving average to decrease after having increased first.

3.5 The total age of players in the pool

The graphs in Appendix A suggest the possibility that the presence of any single 5% information deficiency or combination of 5% information deficiencies increases the total pool age (total amount of IPD games played by all players in the pool after a generation) in each generation when compared to the experiment of the same memory size but without any 5% information deficiency.

In order to measure that one experiment has a statistically significant lower mean total pool age when compared to another experiment, a one-tail two-sample t-test for the mean accounting for unequal variance has been performed on each generation, with a significance level of 5%.

These statistical tests have been performed to look at whether the absence of any one or combination of 5% information deficiencies decreases the total pool age. Statistical tests have also been performed for each information deficiency, to test whether their absence decreases the total pool age in each generation. The results of these tests are found in Table 5.

No. lower	No. higher	MS	Both	One	Expected	Concluded	Count	Total	Last fail
1	2	1	...	W	Y	Y	598	598	...
1	3	1	...	L	Y	Y	598	598	...
1	4	1	...	L, W	Y	Y	598	598	...
2	4	1	W	L	Y	Y	598	598	...
3	4	1	L	W	Y	Y_a	594	598	375
5	6	2	...	D	Y	Y	598	598	...
5	7	2	...	W	Y	Y_a	596	598	9
5	9	2	...	L	Y	Y	598	598	...
5	8	2	...	W, D	Y	Y_a	597	598	8
5	10	2	...	L, D	Y	Y_a	597	598	8
5	11	2	...	L, W	Y	Y_a	596	598	9
5	12	2	...	L, W, D	Y	Y_a	596	598	9
6	8	2	D	W	Y	N_q	548	598	397
6	10	2	D	L	Y	Y_a	595	598	19
7	8	2	W	D	Y	Y_a	597	598	319
7	11	2	W	L	Y	Y	598	598	...
9	10	2	L	D	Y	Y_a	596	598	10
9	11	2	L	W	Y	N_q	564	598	579
8	12	2	W, D	L	Y	Y_a	590	598	35
10	12	2	L, D	W	Y	N	440	598	583
11	12	2	L, W	D	Y	Y	598	598	...
13	14	3	...	D	Y	Y_a	596	598	10
13	15	3	...	W	Y	Y_a	596	598	6
13	17	3	...	L	Y	Y_a	586	598	23
13	16	3	...	W, D	Y	Y	598	598	...
13	18	3	...	L, D	Y	Y_a	591	598	18
13	19	3	...	L, W	Y	Y_a	582	598	23
13	20	3	...	L, W, D	Y	N_q	576	598	38
14	16	3	D	W	Y	N	497	598	555
14	18	3	D	L	Y	Y_a	596	598	8
15	16	3	W	D	Y	Y_a	591	598	22
15	19	3	W	L	Y	N_q	578	598	45
17	18	3	L	D	Y	Y_a	586	598	47

17	19	3	L	W	Y	N	440	598	519
16	20	3	W, D	L	Y	N	496	598	131
18	20	3	L, D	W	Y	N	18	598	600
19	20	3	L, W	D	Y	N_q	537	598	119

Table 5: Results of the statistical tests on the average total age of the player pool per generation.

4 Results

This section aims to draws conclusions on the effects of the presence/absence of the different 5% information deficiencies based on the statistical tests (so the tables) presented in the last section.

4.1 The amount of PD games in which both players cooperate

For memory size 1, 2 and 3, the presence of 5% wrong information decreases the amount of PD games in which both players cooperate in each generation. There is one experiment for which this statistically significant decrease has been observed in only 599 out of 600 generations. In the other experiments it had been observed for all generations.

In some of the comparisons between experiments, the presence of 5% lost information decreases the number of games in which both players cooperate per generation. This has been observed for 600/600 iterations with the addition of 5% lost information to 5% delayed information for memory size 2 and with the addition of 5% lost information to any experiment with some information deficiency for memory size 3.

Furthermore, for memory size 2, the addition of 5% lost information to an experiment containing 5% delayed information seems to cause a statistically significant decrease in a much greater number of iterations than the addition of 5% lost information to an experiment without delayed information.

In the comparisons of experiments of memory size 3, the presence of 5% delayed information reduces the amount of PD games in which both players cooperate in each generation given that both experiments contain at least one common 5% information deficiency.

4.2 The average payoff received by players

For memory size 1, 2 and 3, the addition of 5% wrong information decreases the average payoff received by players in each generation. There is one experiment for which this statistically significant decrease has been observed in only 595 out of 600 generations. In the other experiments it had been observed for all generations.

For memory size 1, the addition of 5% lost information has led to a statistically significant decrease in the average payoff received by players in 584/600 and 596/600 generations.

For memory size 2, the addition of 5% lost information has led to a statistically significant decrease in the average payoff received by players when compared to the experiments containing the 5% delayed information deficiency in 599/600 and 584 generation.

For memory size 3, the presence of 5% lost information, when comparisons are between experiments which share at least one other form of information deficiency, leads to a decrease in the average player payoff observed in each generation.

For memory size 2, the presence of 5% delayed information, when both experiments contain only the 5% lost information deficiency, leads to a decrease in the average player payoff observed in 597/600 generations.

For memory size 3, the addition of 5% lost information, when compared to experiments which already have some form of information deficiency, leads to a decrease in the average player payoff. In one experiment that effect has been observed in 598/600 generations. In the other two experiment the effect has been observed in every generation.

4.3 On the moving average

The presence of a 5% information deficiency of any kind seems to increase the number of the generations it takes to reach the point for which the simple moving average over the number of games in which both players cooperate per generation first decreases after having increased.

4.4 The total age of player in the pool

The total amount of IPD games played by all players after a generation (which will be referred to as total pool age) is always the same for the first two generations. This means the first generations are ignored with results to statistical tests. A statistically significant result can at most be observed for 598 generations.

The presence of any single 5% information deficiency or combination of 5% information deficiencies, when compared to the experiment of the same memory size without any information deficiency, has led to an increase the total age of all players in the pool in at least 596/598 generations for at least one of the three different memory sizes.

Furthermore, the addition of 5% lost or delayed information, when comparing experiments which have some common information deficiency, has been observed to be able to increase the total pool age in each generation in at least one comparison of experiments. The addition of 5% wrong information has this effect observed in at most 596/598 generations.

5 Conclusion

This section discusses the observed effects of lost, wrong and delayed information on the evolution of cooperation for the Iterative Prisoner's Dilemma. It also discusses further avenues of research based on the research performed in this paper.

5.1 Observed effects of the information deficiencies

In the previous section, the observations that emerged from statistical analysis have been discussed. This subsection aims to draw general conclusions from these observations in order to answer the research questions stated earlier in the paper.

In the experiments that have been performed, the presence of 5% wrong information seems to consistently decrease the amount of PD games in which both players cooperate as well as the average payoff a player receives. The addition of 5% lost or delayed information is able to cause such effect as well, but this effect is not observed in all comparisons between experiments.

The addition of any of the 5% information deficiencies causes the point at which the simple moving average first decreases after increasing to be at a later generation, when compared to the experiment without that specific information deficiency.

The addition of any single 5% information deficiency or combination of 5% information deficiencies, when compared to the experiment of the same memory size without any information deficiency, is able to increase the total age of all players in the pool. The addition of any single 5% information deficiency, when compared to the experiment of the same memory size, might increase the total age of all players in the pool. This means that any of the 5% information deficiencies is able to slow down the rate at which the average player is removed from the pool. The performed experiments are far from being able to provide generalizable conclusions with regards to all of the overall effects lost and delayed information might have.

This paper has managed to demonstrate how the presence of certain information deficiencies can have various effects on the evolution of cooperation. It has also shown that, in the experiments performed, the presence of information deficiencies does not stop cooperate behavior from evolving entirely. Clearly, cooperative behavior does not only evolve in ideal circumstances.

A method of investigating the possible of effects of different information deficiencies has been laid out. The following subsection describes how the research performed in this paper might be expanded.

5.2 Proposals for further research

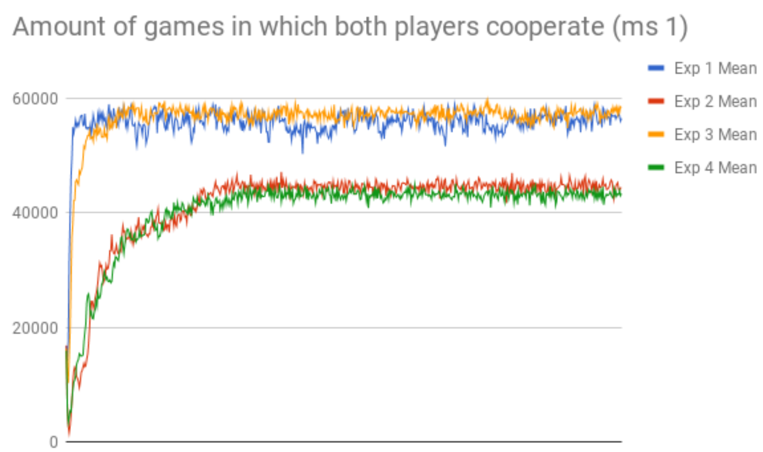
One important limitation in the research conducted was that information deficiencies could only occur at rate of either 0% or 5%. Expanding these rates to other values might complicate analysis of the results obtained, but would allow for a better overview of their effects.

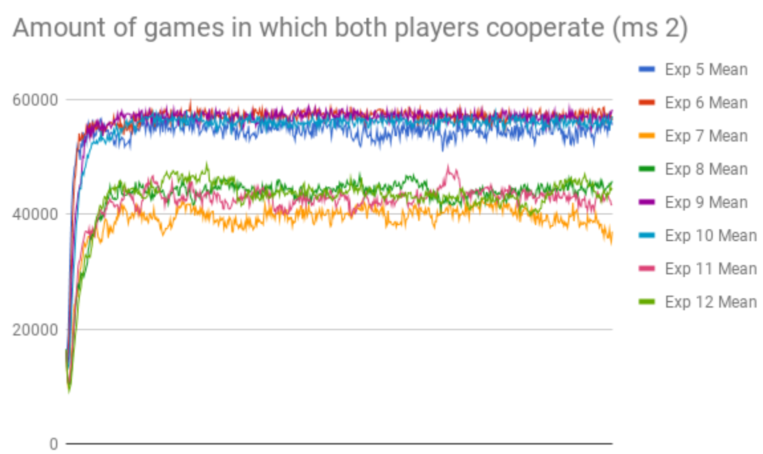
Furthermore, there are some differences between results of different memory sizes. These could be caused by, for example, the specifics of the mutation algorithm in combination with the player strategy implementation. They may also be caused by longer memory allowing for longer delayed information or different strategies being preferable for different memory lengths. At any rate, research with regards to different player strategy representations and mutation algorithms as well as player pool dynamics could provide insight into the influence they might have.

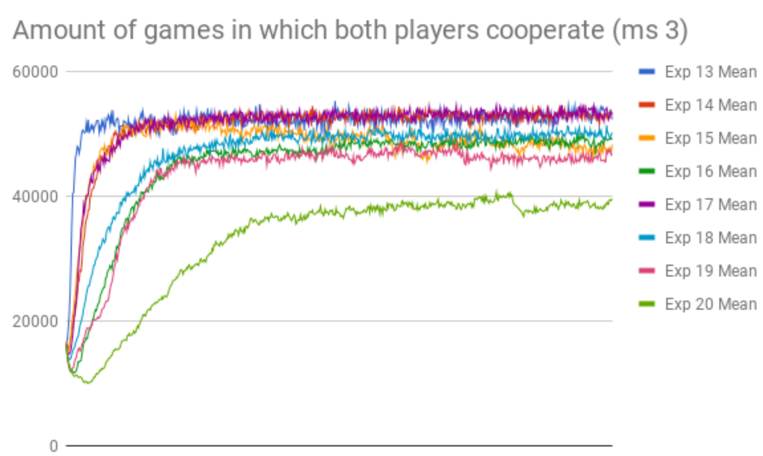
Moreover, some results, such as the comparison between total pool age for experiments 18 & 20 might hint at a special relation between lost and delayed information, since players cannot immediately tell which is which when memory size is greater than 1. This might also inspire further investigation.

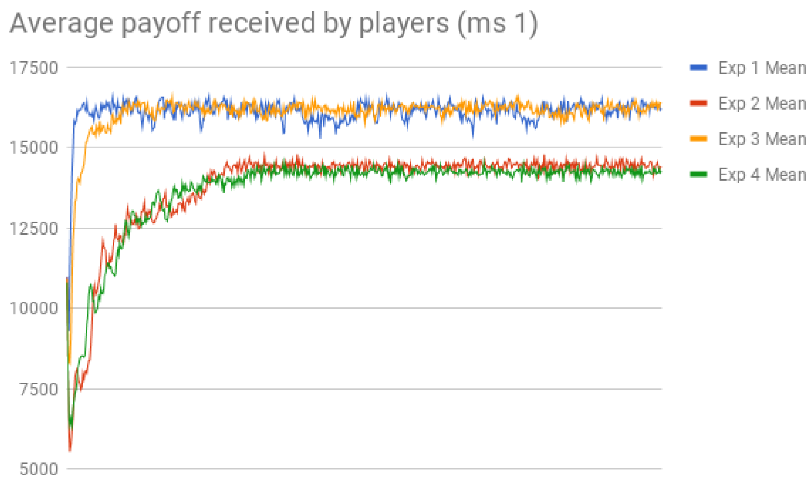
6 Appendix A

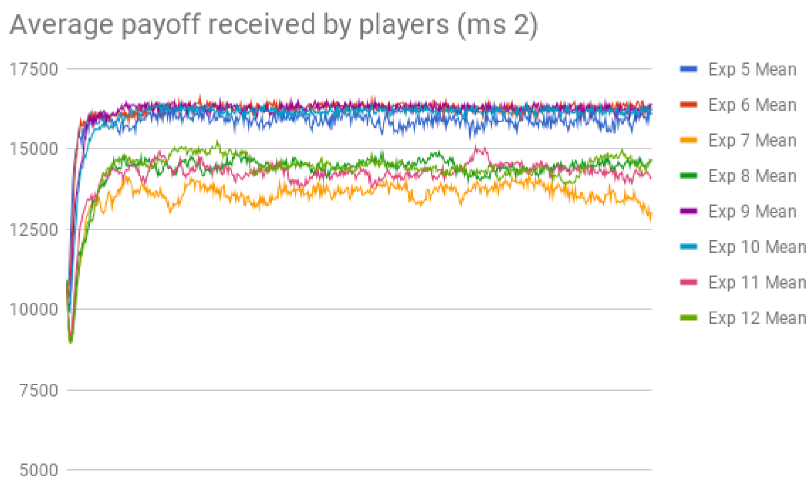
The x-axis of all graphs is the number of iterations.

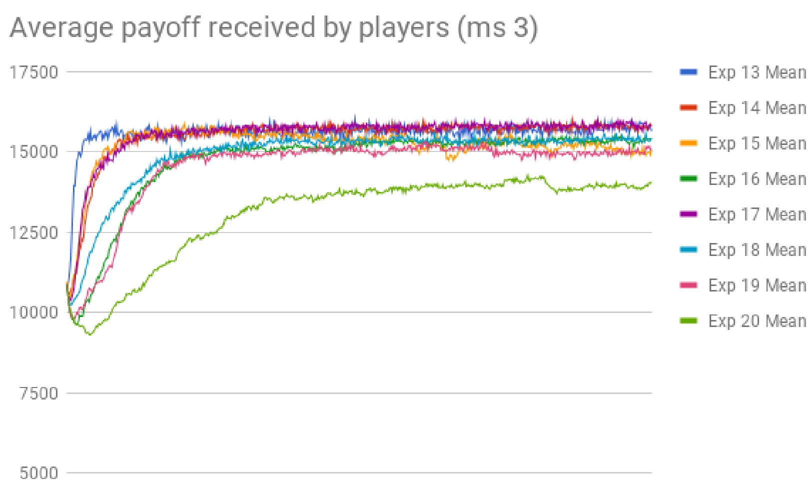


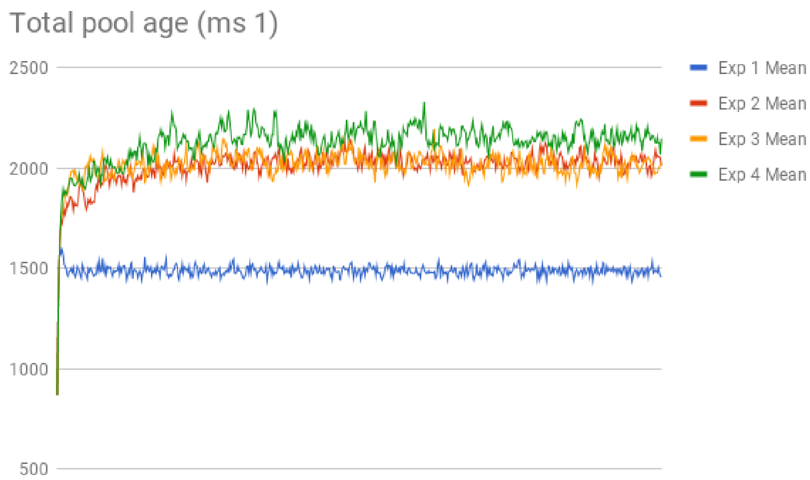


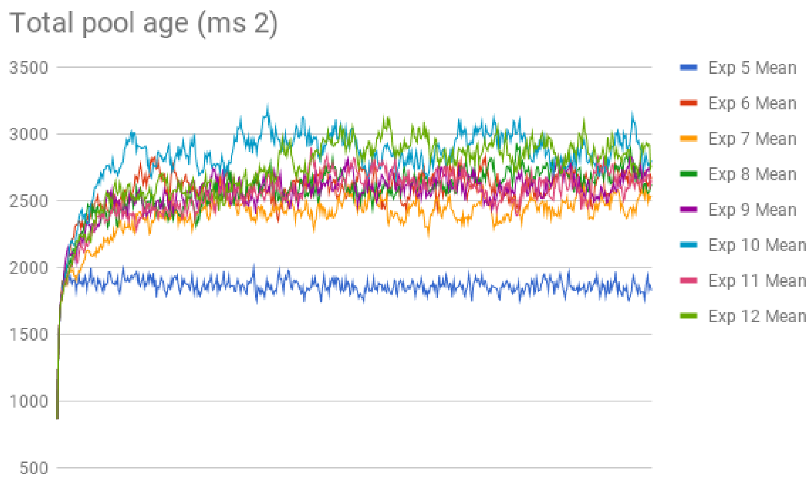


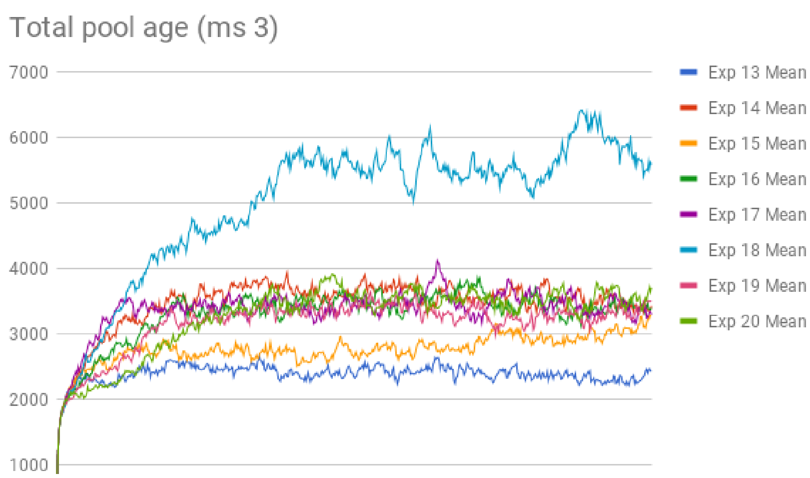

Average payoff received by players (ms 1)
17500
15000
12500
10000
7500
5000
Exp 1 Mean
Exp 2 Mean
Exp 3 Mean
Exp 4 Mean


Average payoff received by players (ms 2)
17500
15000
12500
10000
7500
5000
Exp 5 Mean
Exp 6 Mean
Exp 7 Mean
Exp 8 Mean
Exp 9 Mean
Exp 10 Mean
Exp 11 Mean
Exp 12 Mean


Average payoff received by players (ms 3)
17500
15000
12500
10000
7500
5000
Exp 13 Mean
Exp 14 Mean
Exp 15 Mean
Exp 16 Mean
Exp 17 Mean
Exp 18 Mean
Exp 19 Mean
Exp 20 Mean


Total pool age (ms 1)
2500
2000
1500
1000
500
Exp 1 Mean
Exp 2 Mean
Exp 3 Mean
Exp 4 Mean


Total pool age (ms 2)
3500
3000
2500
2000
1500
1000
500
Exp 5 Mean
Exp 6 Mean
Exp 7 Mean
Exp 8 Mean
Exp 9 Mean
Exp 10 Mean
Exp 11 Mean
Exp 12 Mean


Total pool age (ms 3)
7000
6000
5000
4000
3000
2000
1000
Exp 13 Mean
Exp 14 Mean
Exp 15 Mean
Exp 16 Mean
Exp 17 Mean
Exp 18 Mean
Exp 19 Mean
Exp 20 Mean

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