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Prof. Dr. May R Berenbaum  
Editor-in-Chief

Proceedings of the National Academy of Sciences

# Max Planck Research Group Dynamics of Social Behavior

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Dear Prof. Dr. Berenbaum,

I am pleased to submit our research paper entitled “**Conditional cooperation with longer memory**” by Nikoleta E. Glynatsi, Martin A. Nowak and Christian Hilbe for your consideration for publication in *Proceedings of the National Academy of Sciences*.

Direct reciprocity is a widespread mechanism for the evolution of cooperation. This mechanism explains why people return favors, show more effort in group tasks when others do, or cease cooperating when they feel exploited. Traditionally, most theoretical research on the evolution of reciprocity focuses on strategies that condition only on the outcome of the previous outcome, on memory-1 strategies. This focus is because a formal analysis of strategies with more than one-round memory has been difficult for various reasons: firstly, as the memory length increases, strategies become harder to interpret; secondly, the number of strategies, and the time it takes to compute their payoffs, increases dramatically with .

To address these challenges, in this manuscript, we focus on an easy-to-interpret subset of memory- strategies, namely reactive- strategies. Capturing the basic premise of conditional cooperation, reactive- strategies depend solely on the co-player's actions during the last rounds. While explicitly characterizing all Nash equilibria among memory- strategies has been challenging, we demonstrate the feasibility of such characterization for reactive- strategies.

Specifically, we developed an algorithm to verify whether a given reactive- strategy is a *partner strategy*. Partner strategies are particularly of interest because they are capable of sustaining full cooperation as a Nash equilibrium. We are able to fully characterize reactive- partner strategies for and , as well as reactive- counting strategies. A reactive- counting strategy records how often the co-player has cooperated during the last n rounds. Our results build upon a technical result: to test whether a reactive- strategy is Nash, one needs only to consider deviations towards deterministic self-reactive- strategies (strategies considering only their own last moves).

Furthermore, we performed evolutionary simulations to study the impact of memory length on cooperation rates. These simulations reveal that longer memory increases the average cooperation rate because natural selection chooses partners. We find that this holds for reactive- strategies but not for reactive counting strategies, highlighting that paying attention to the sequence of moves is necessary for reaping the advantages of longer memory.

Overall, our results provide important insights into the logic of conditional cooperation when players have more than one-round memory. We demonstrate that partner strategies exist for all repeated prisoner's dilemmas and for all memory lengths.

We believe that our paper aligns with the scope and objectives of *Proceedings of the National Academy of Sciences* and will contribute to the ongoing scientific discourse in the field of cooperative behaviors. Therefore, we would be delighted if this article could be considered for publication in your journal.

As handling editors, Cook, Karen S. and *someone else* would certainly be excellent candidates. As potential referees, we would like to suggest the following:

* **Alexander J. Stewart** ([ajs50@st-andrews.ac.uk](mailto:ajs50@st-andrews.ac.uk), University of St Andrews) is an expert in models of direct reciprocity.
* **Feng Fu** ([Feng.Fu@dartmouth.edu](mailto:Feng.Fu@dartmouth.edu), Dartmouth University) has written many papers onrepeated games and strategies in repeated games.
* **Xingru Chen** ([kaleda@stanford.edu](mailto:kaleda@stanford.edu), Beijing University of Posts and Telecommunications) is a mathematician interested in direct reciprocity.
* **Max Kleiman-Weiner** ([maxkw@mit.edu](mailto:maxkw@mit.edu), University of Washington) a computational cognitive scientist interest in cooperation.
* **Christoph Hauert** ([christoph.hauert@math.ubc.ca](mailto:christoph.hauert@math.ubc.ca), University of British Columbia) has written many papers on direct reciprocity and on evolutionary game dynamics more generally.

Thank you for considering our submission.

With kind regards,

On behalf of the authors,

Nikoleta E. Glynatsi

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