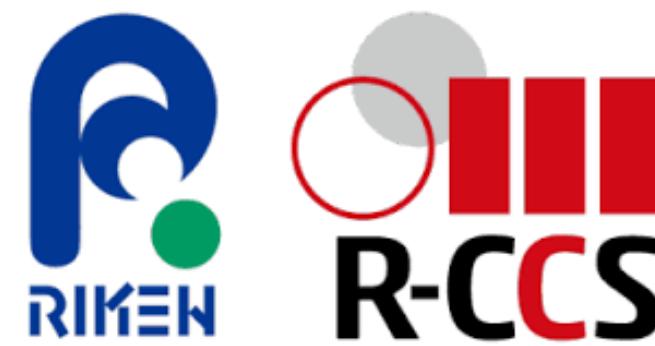
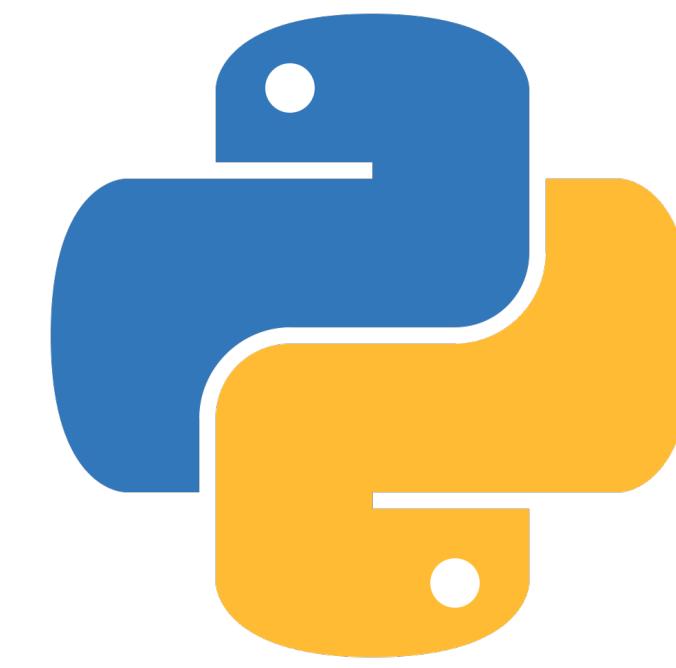
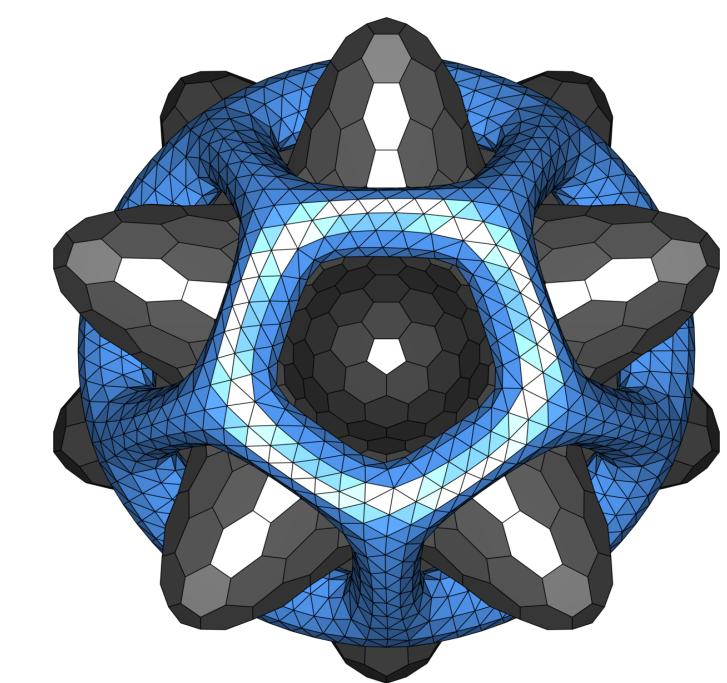
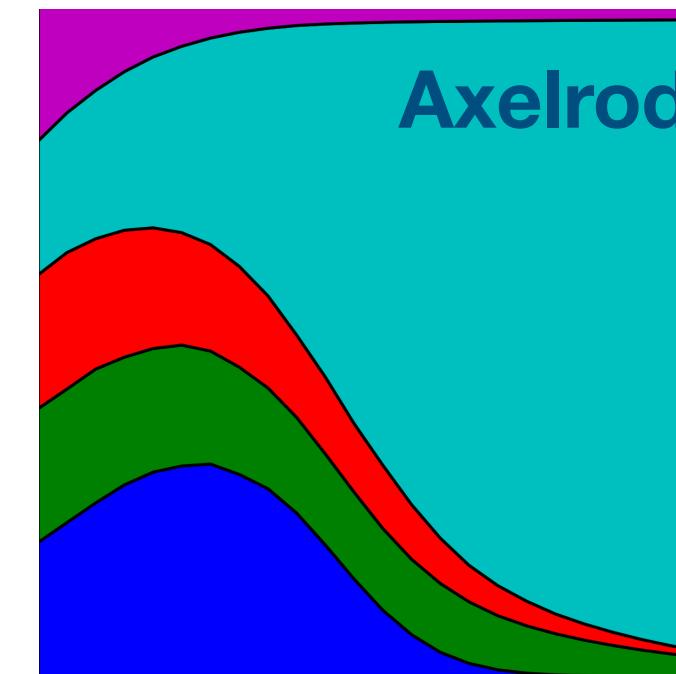
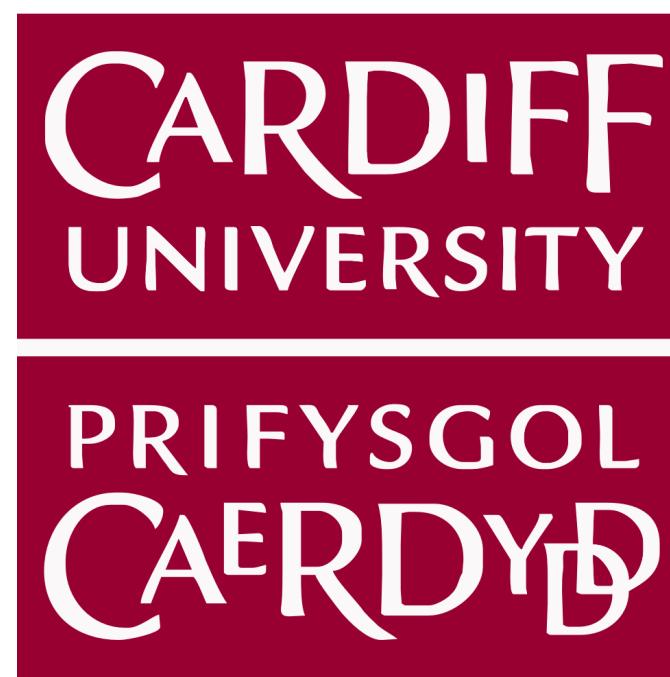


The impact of memory on cooperation

Nikoleta E. Glynatsi

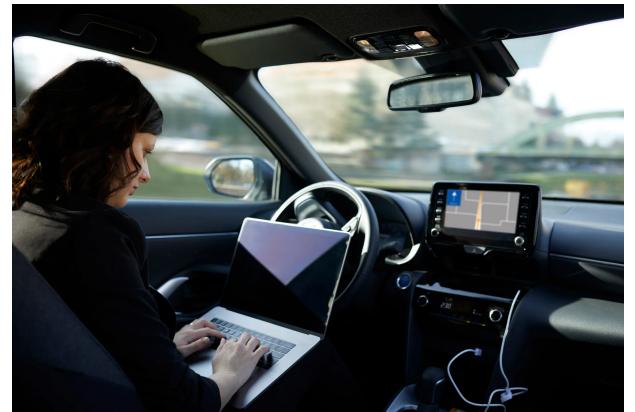




Social Behavior

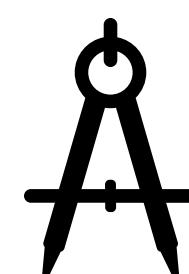
Understand Cooperation

- Advance theoretical models
- Identify factors that can help sustain cooperation
- Train and understand autonomous learning agents

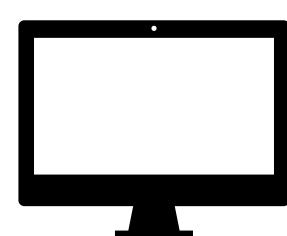


Analysing Scientific Collaboration

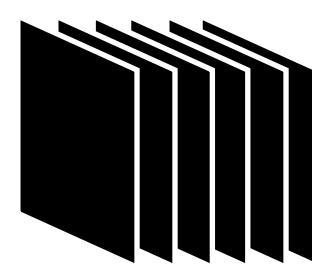
- Assess authors' collaborativeness
- Characterize topics and understand their emergence



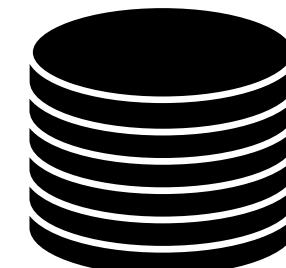
Mathematical Analysis



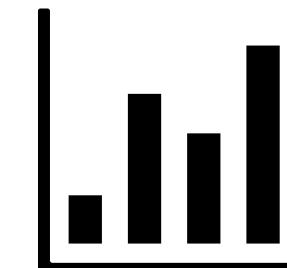
Agent Based
Simulations



Parallel Computing



Data Scraping

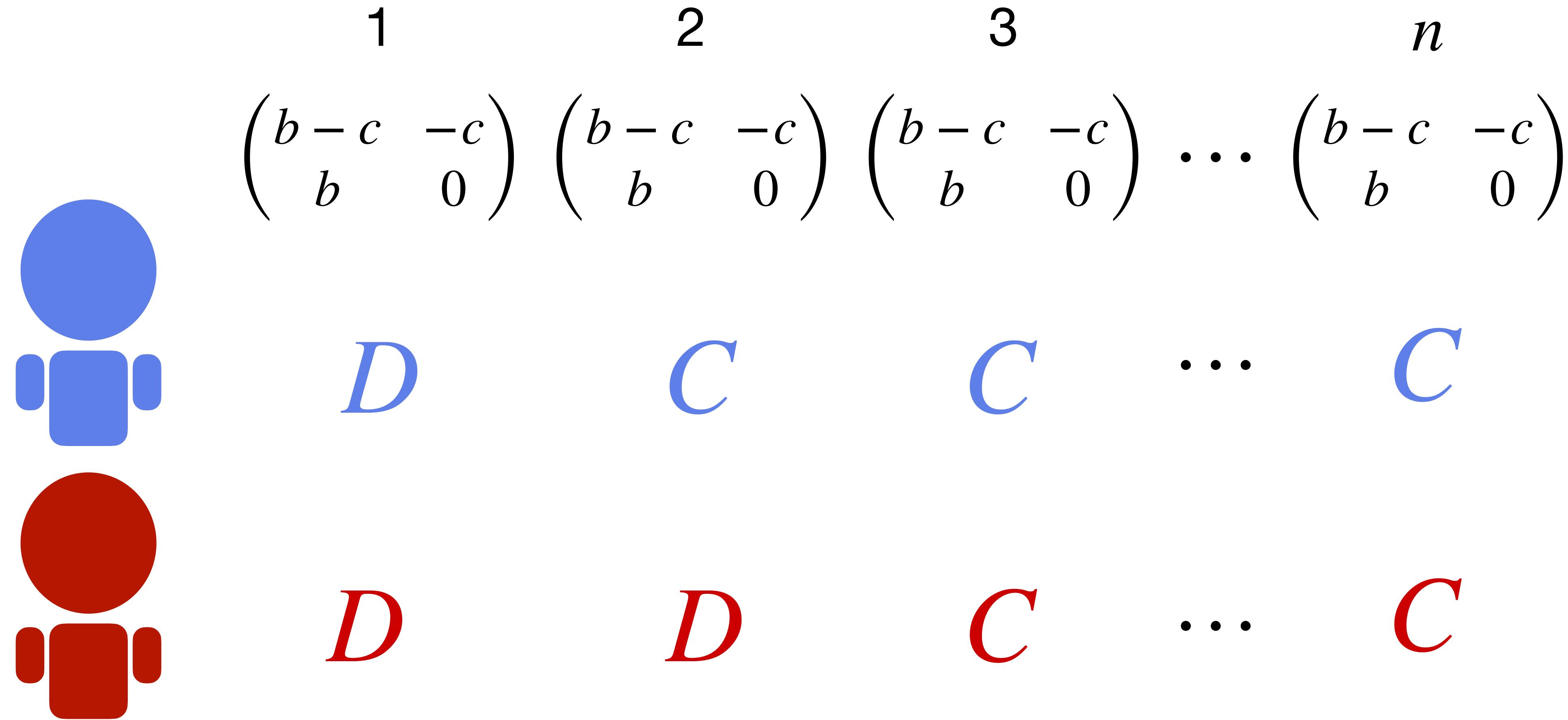


Data Analysis

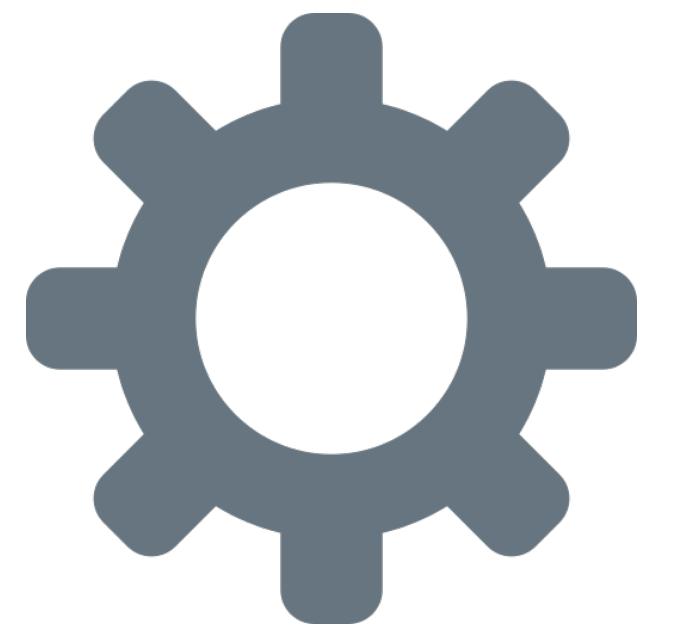
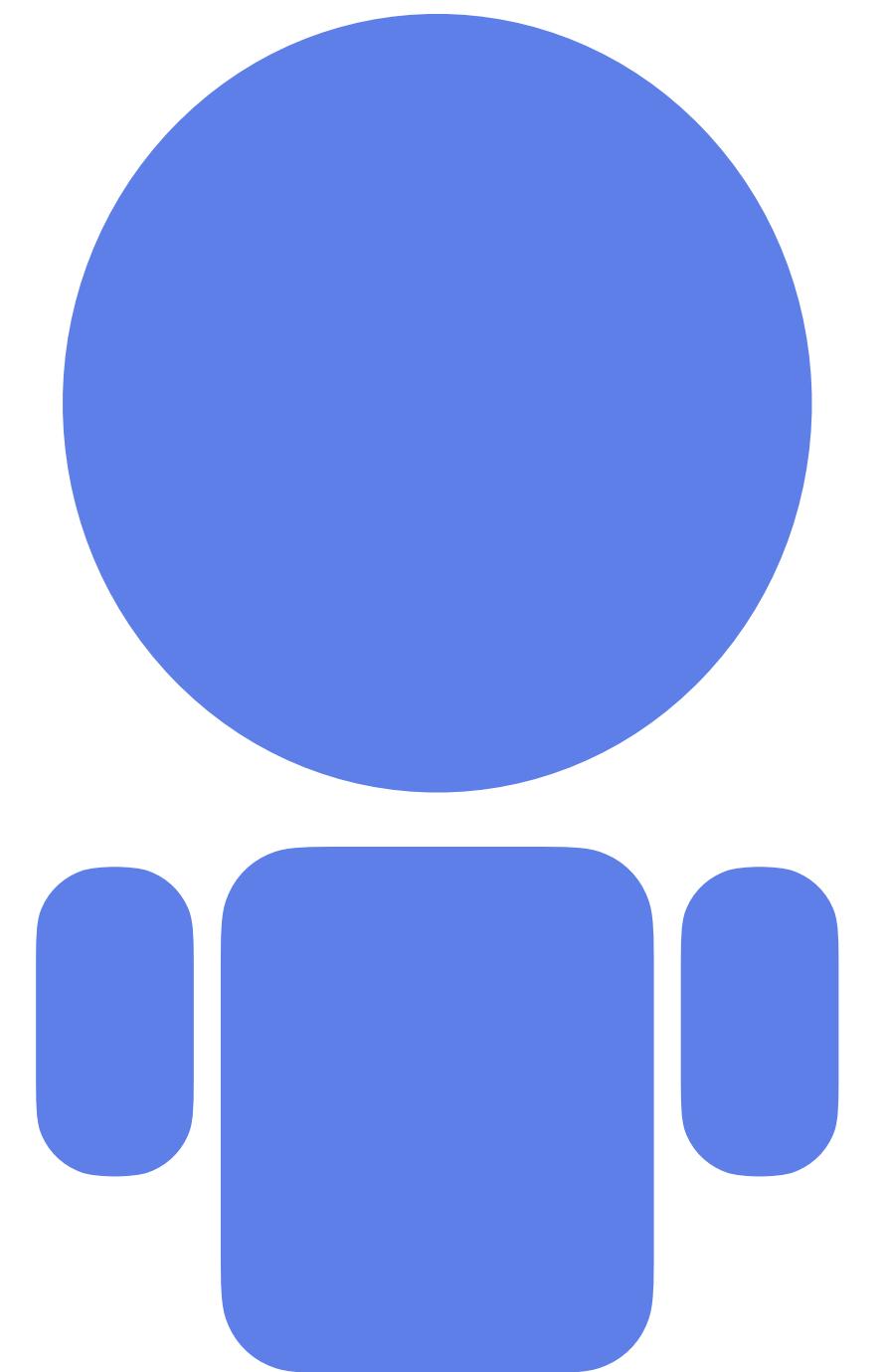
$$\begin{array}{cc} & \begin{matrix} C & D \end{matrix} \\ \begin{matrix} C \\ D \end{matrix} & \left(\begin{matrix} b - c & -c \\ b & 0 \end{matrix} \right) \end{array}$$

Nash Equilibrium

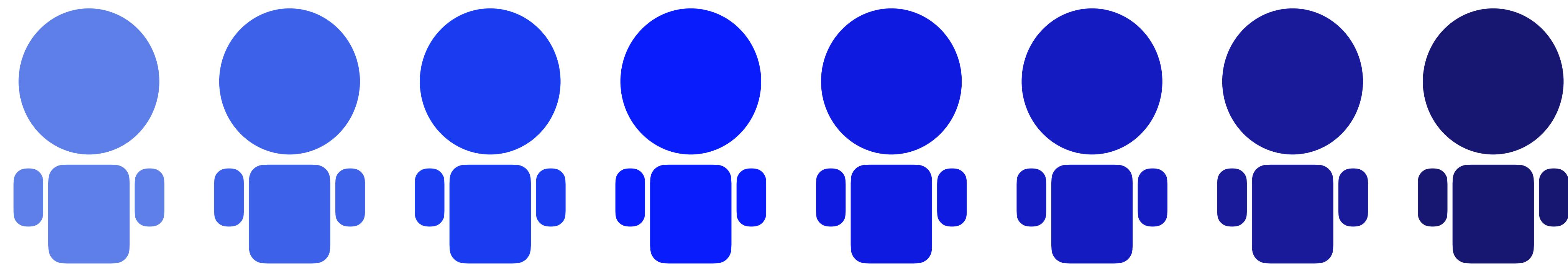
$$b > c > 0$$



Direct reciprocity



remember &
process information



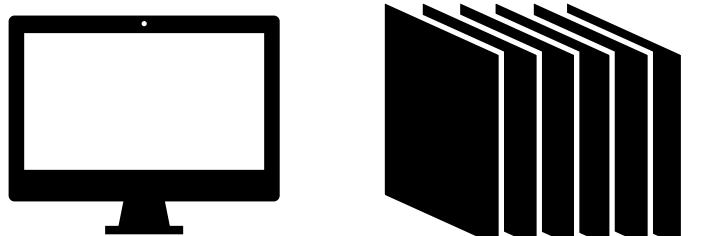
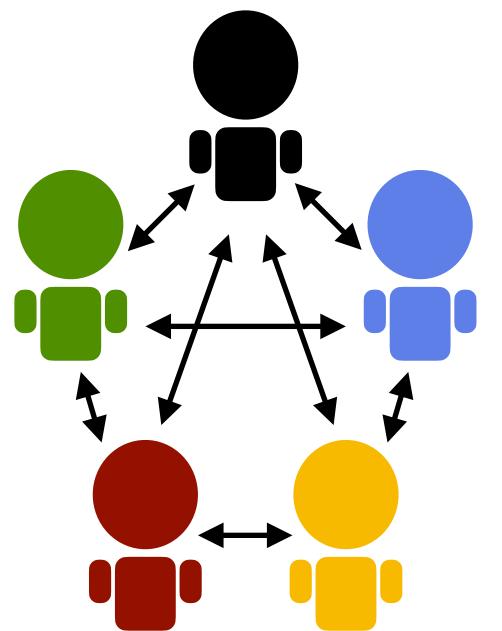
1

memory

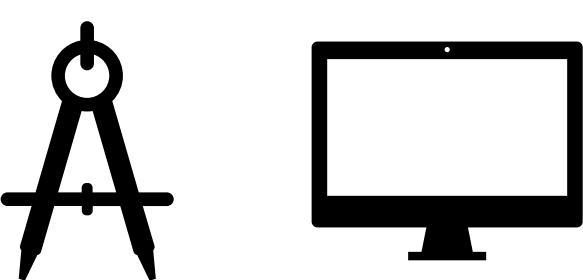
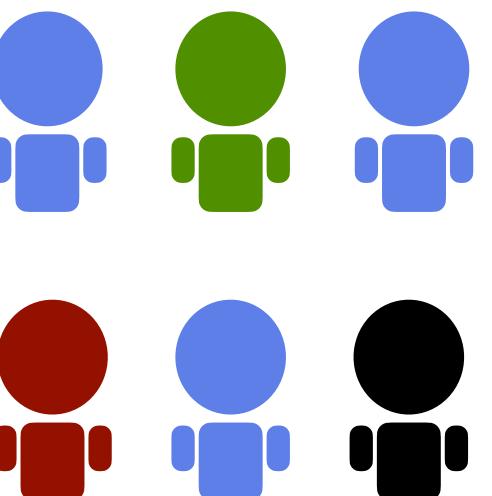
∞

Current Research

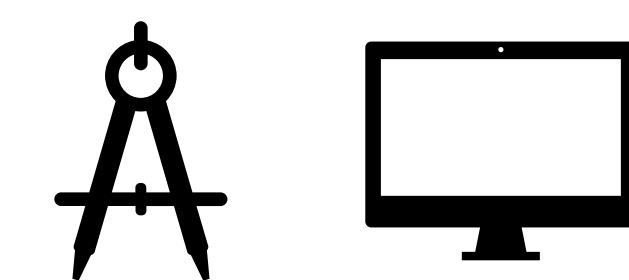
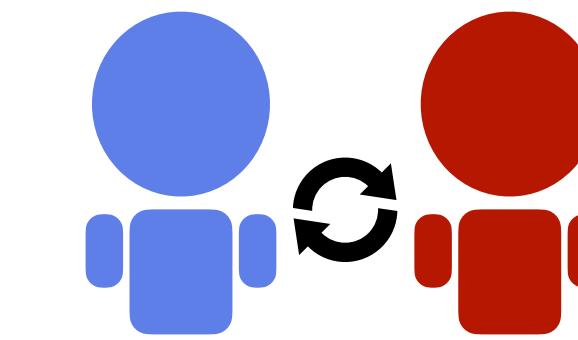
1. Strategies in computer tournaments



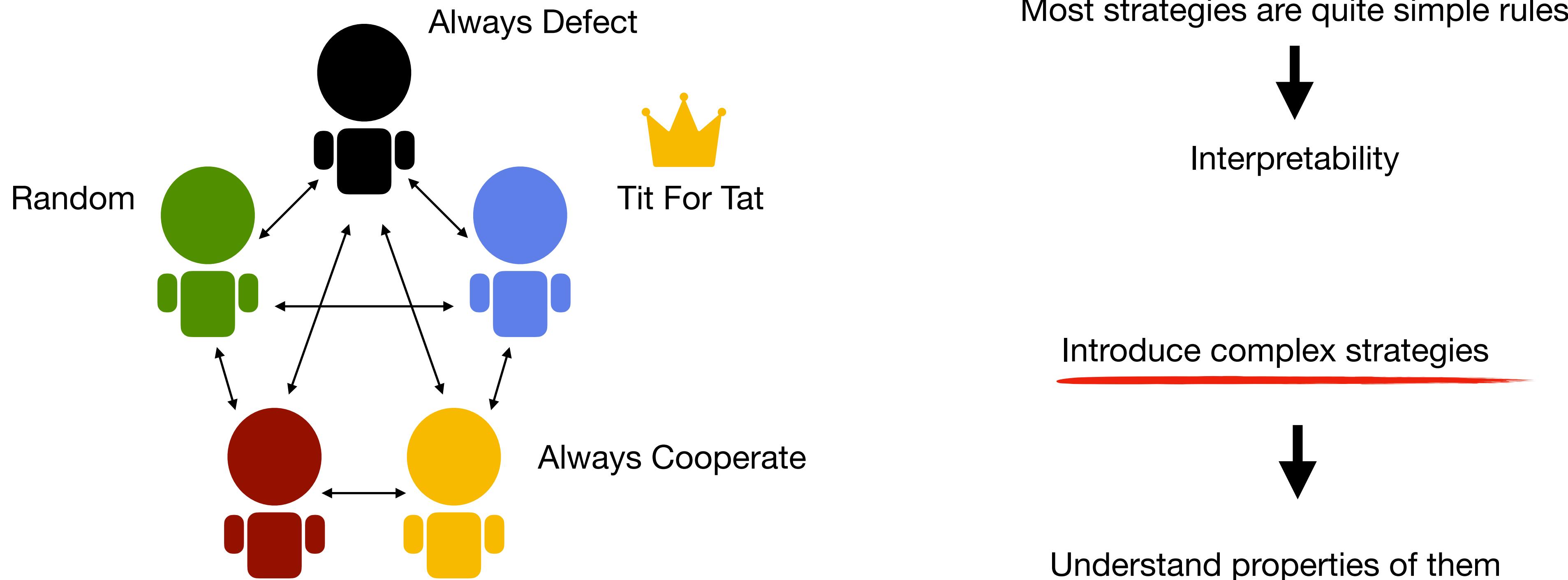
2. Learning in populations



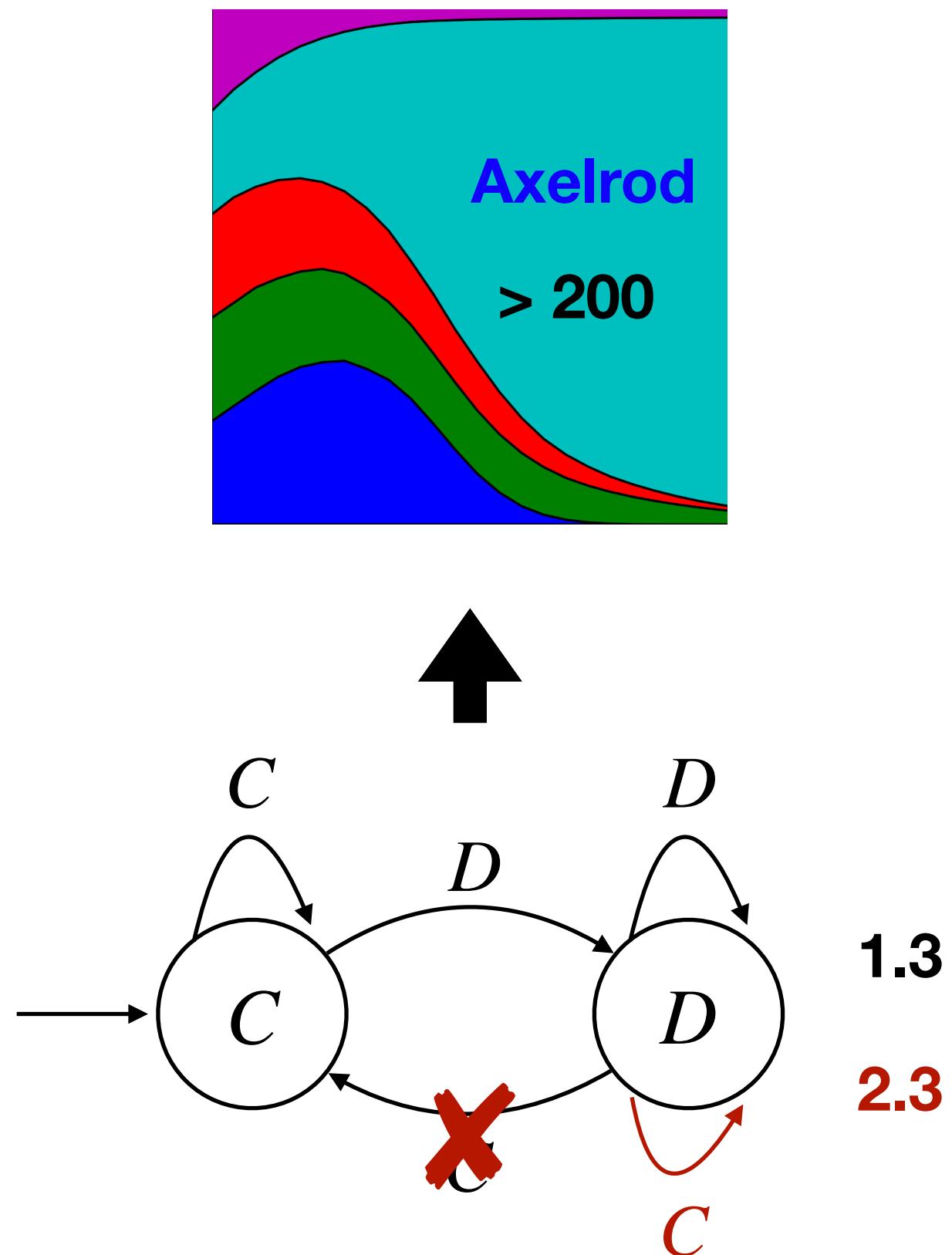
3. Strategies in repeated interactions



1. Strategies in computer tournaments



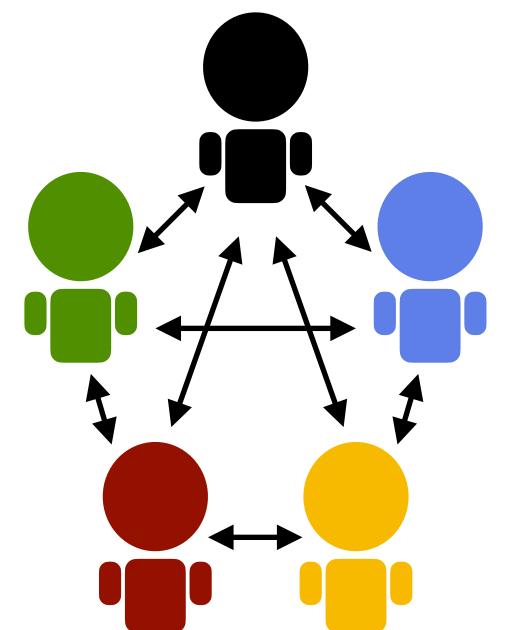
1. Strategies in computer tournaments



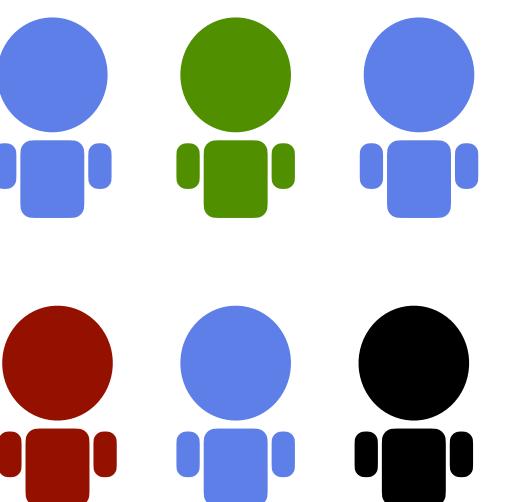
- From the training emerged strategies that were cooperative but also took advantage of simple strategies
- Strategies trained in environments with errors were more adaptable

[1] Reinforcement learning produces dominant strategies for the iterated prisoner's dilemma. <https://doi.org/10.1371/journal.pone.0188046>
[2] Evolution reinforces cooperation with the emergence of self-recognition mechanisms. <https://doi.org/10.1371/journal.pone.0204981>
[3] Properties of Winning Iterated Prisoner's Dilemma Strategies. <https://arxiv.org/abs/2001.05911>

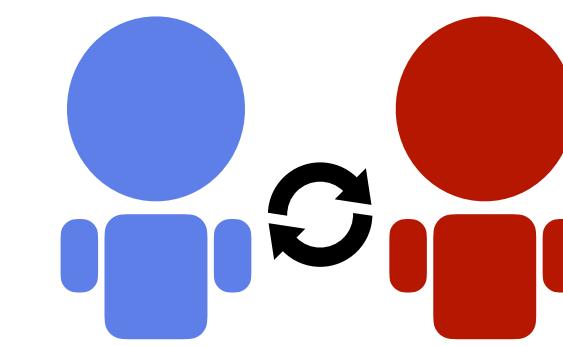
1. Strategies in computer tournaments



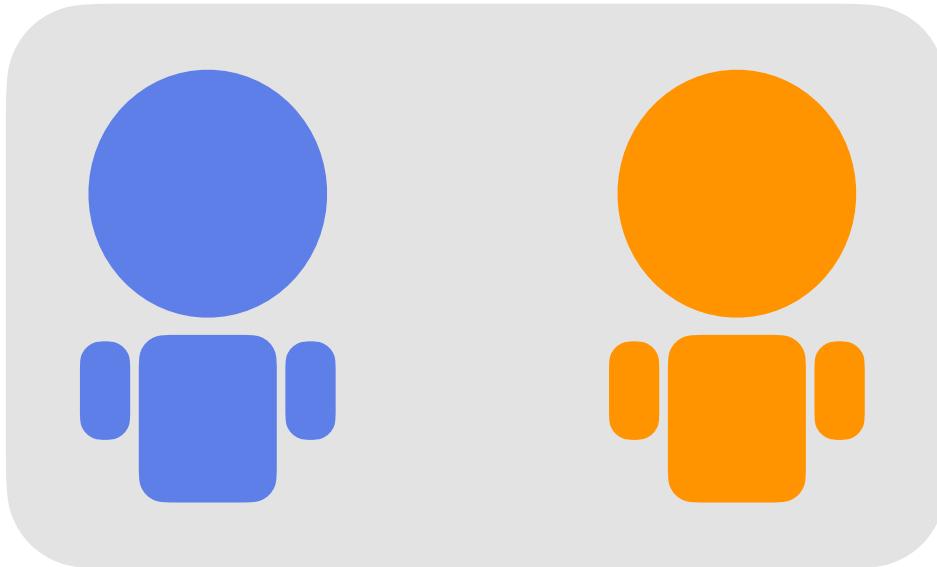
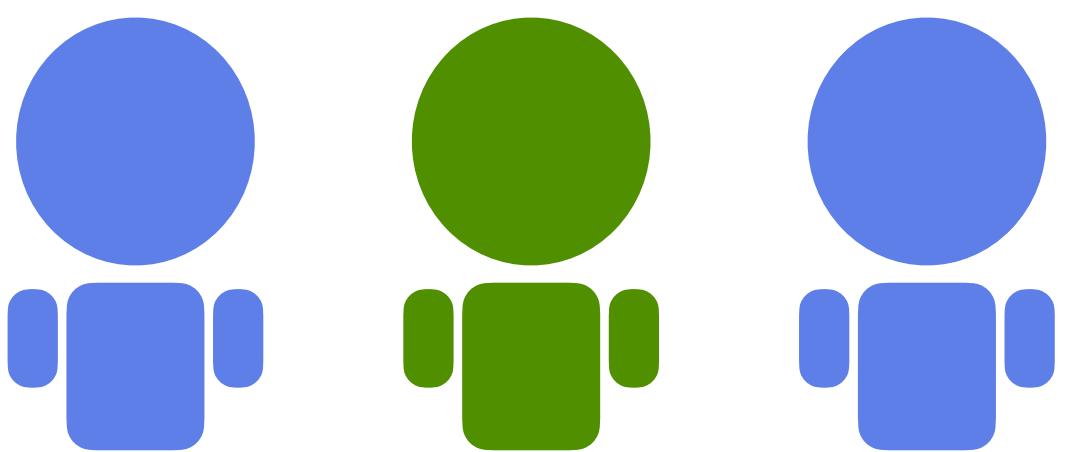
2. Learning in populations



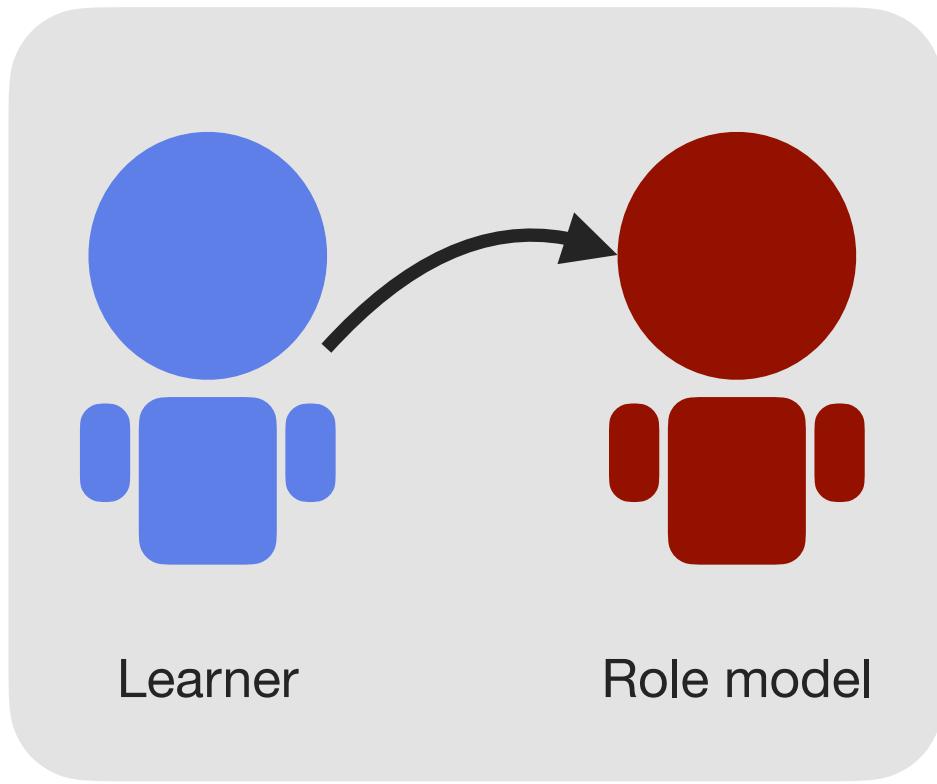
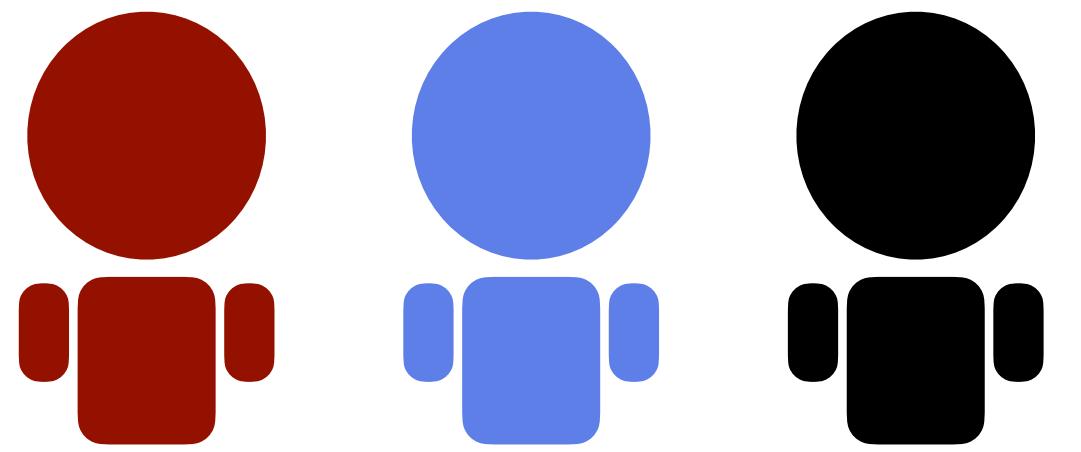
3. Strategies in repeated interactions



2. Learning in populations

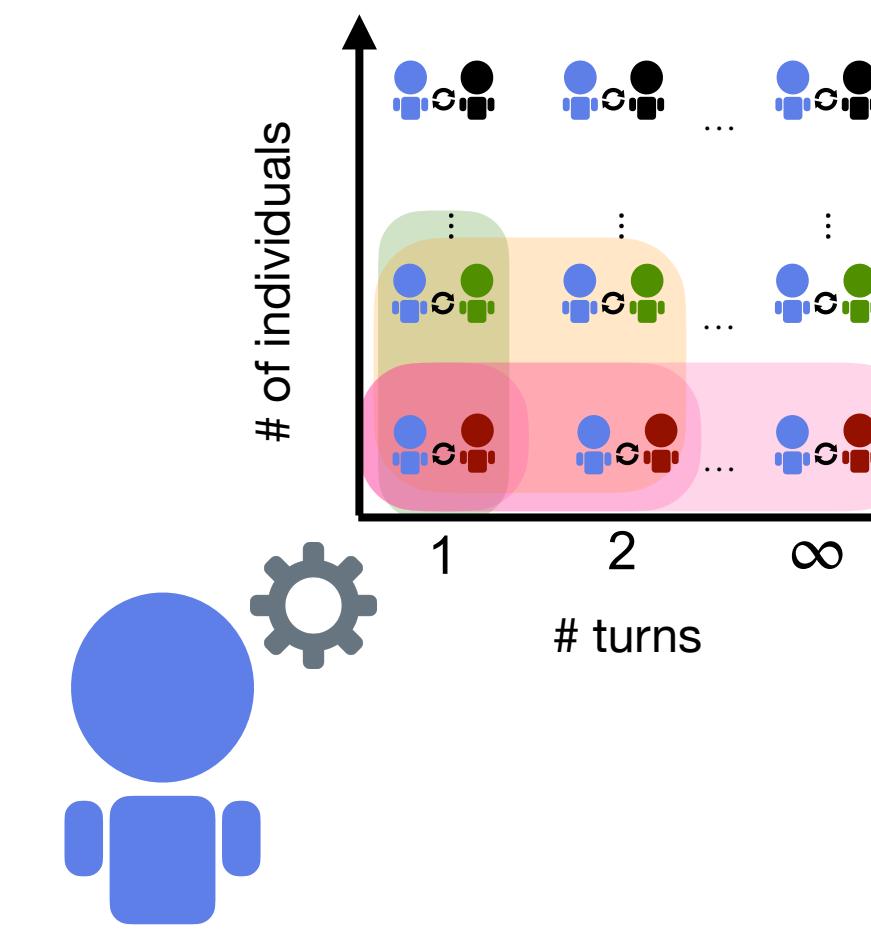
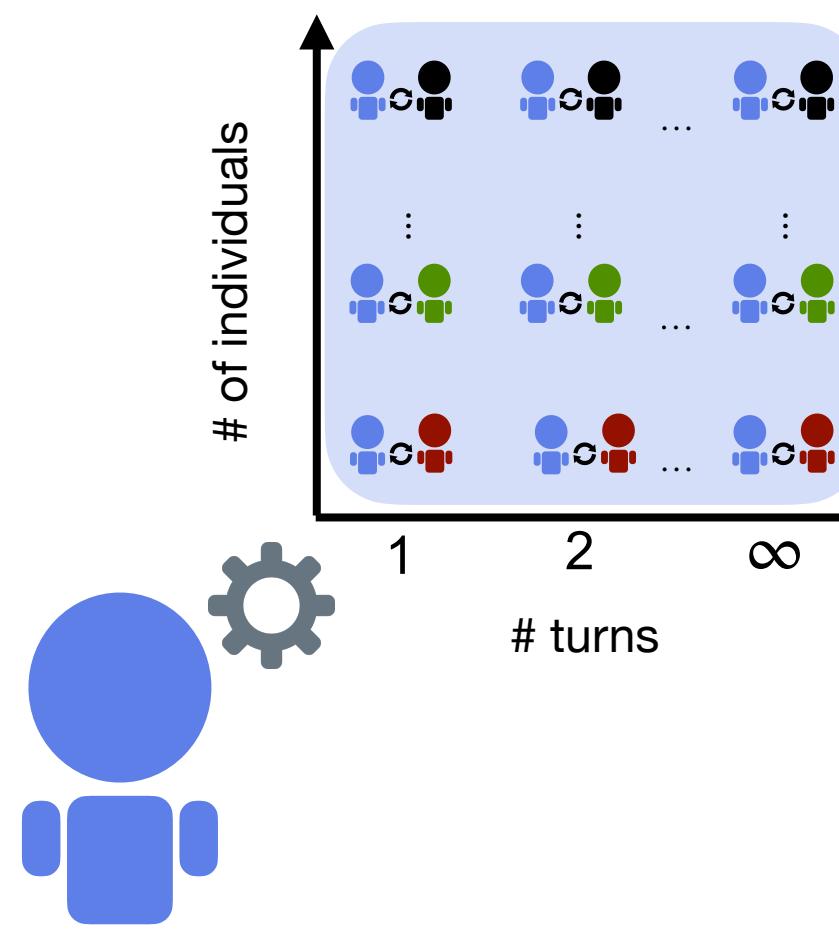
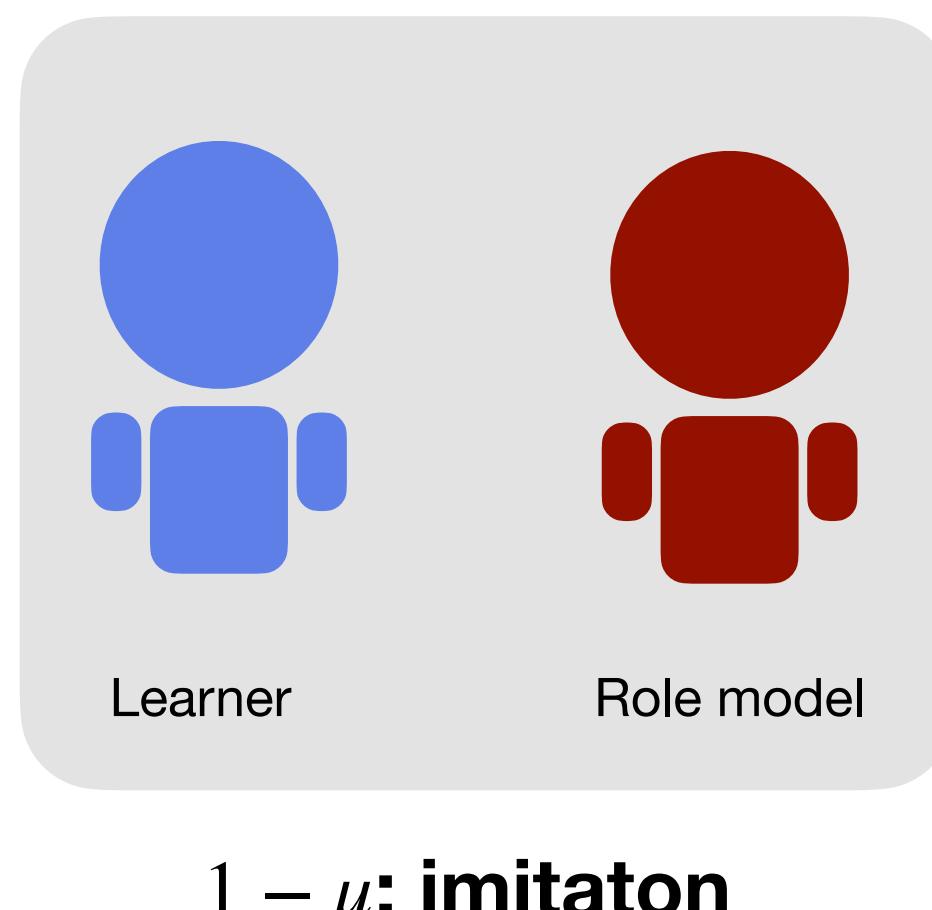


μ : mutation

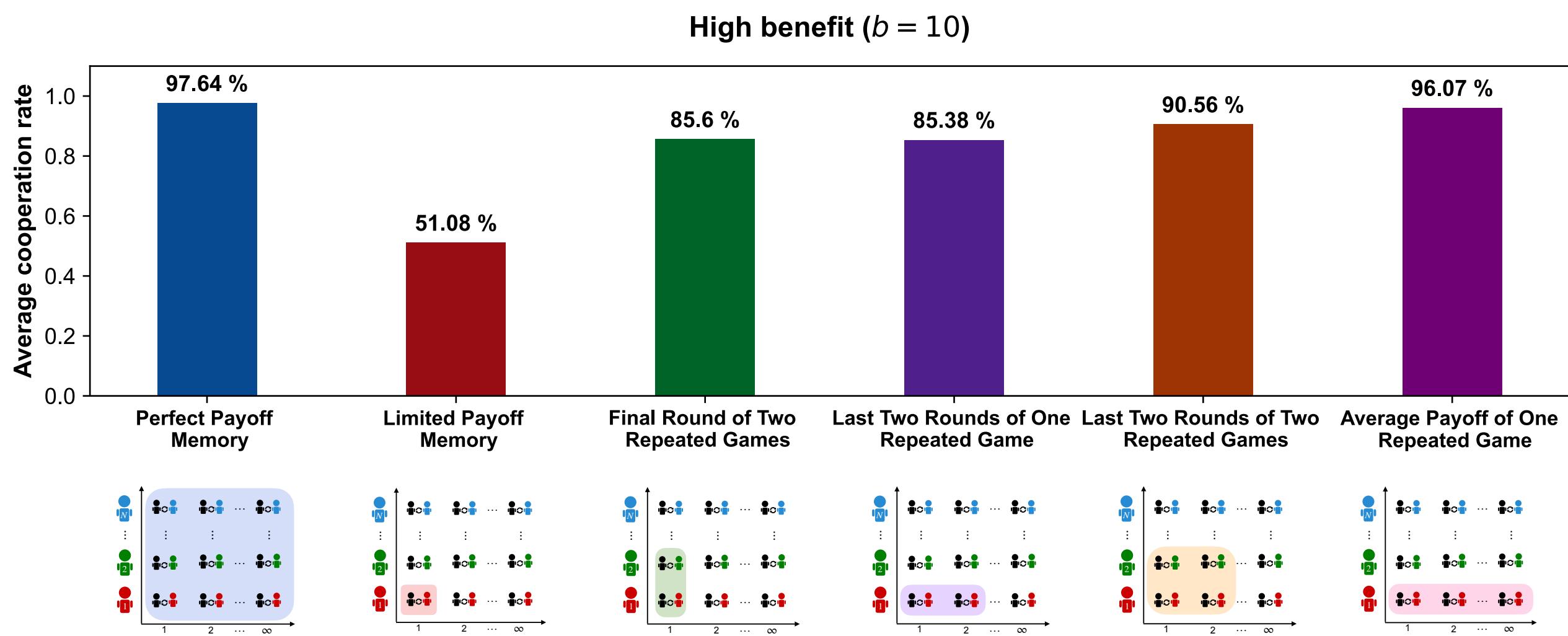


$1 - \mu$: imitation

2. Learning in populations

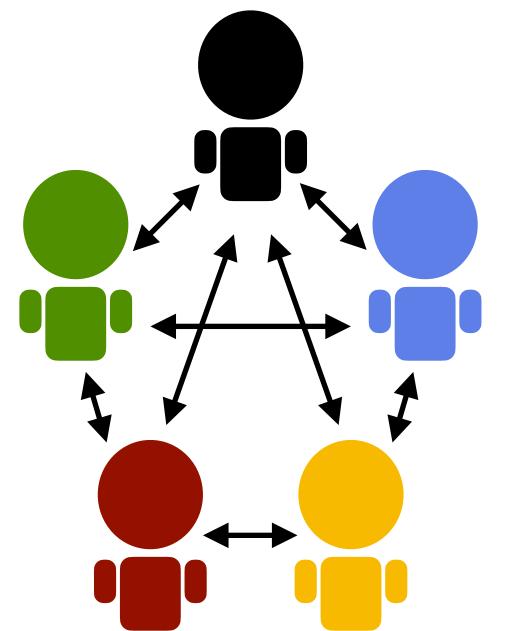


2. Learning in populations

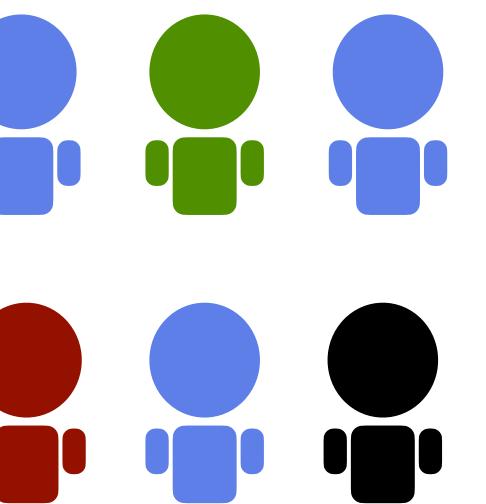


- Cooperation still evolves even with limited memory
- As individuals remember two or three recent interactions, the cooperation rates approach the classical limit

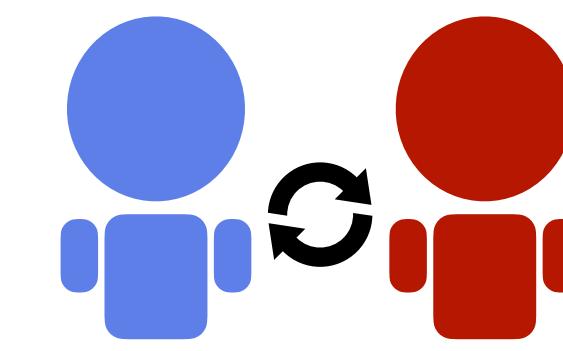
1. Strategies in computer tournaments



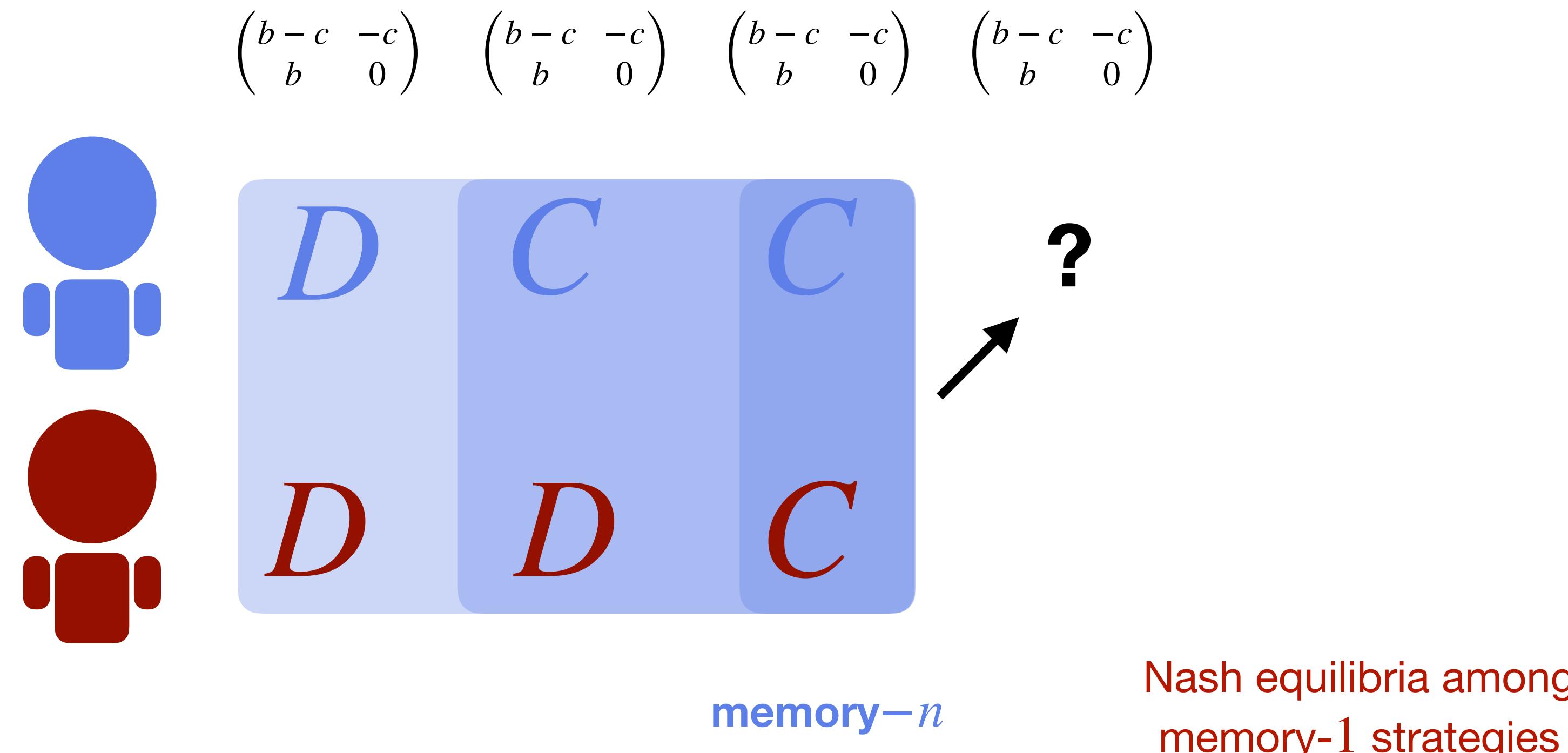
2. Learning in populations



3. Strategies in repeated interactions

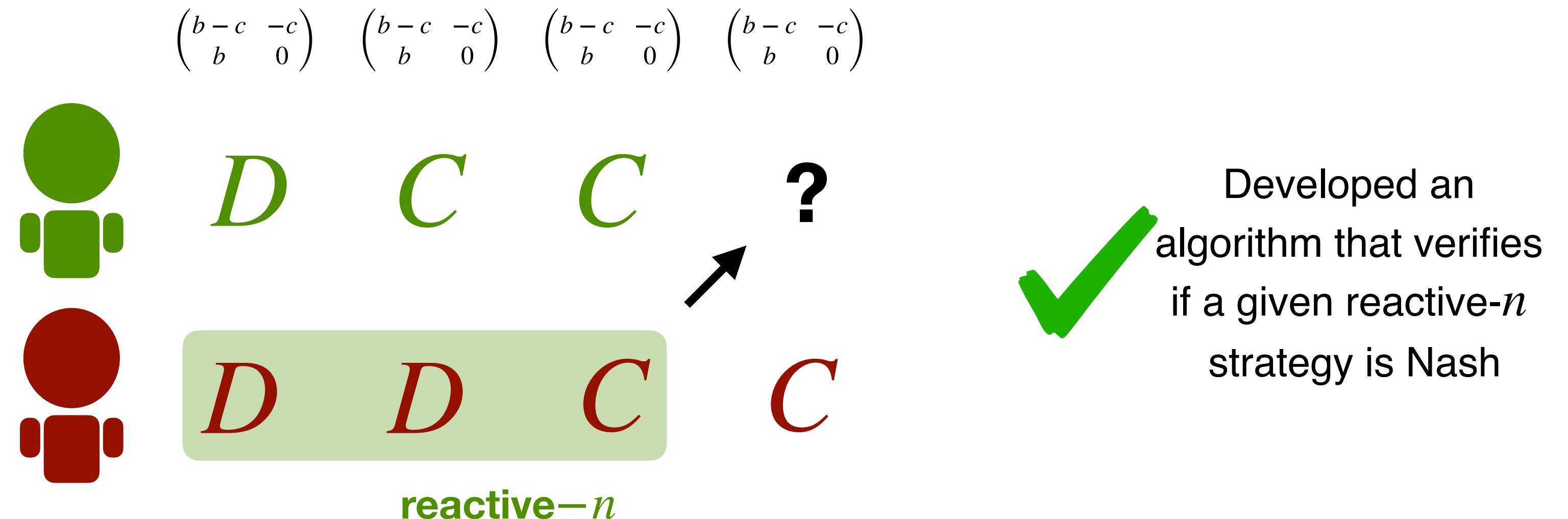


3. Strategies in repeated interactions



3. Strategies in repeated interactions

Can we say anything about Nash equilibria in repeated games with higher memory than $n = 1$?



3. Strategies in repeated interactions

$n = 2$

Theorem. A reactive-2 strategy can be defined as the vector $\mathbf{p} = (p_{CC}, p_{CD}, p_{DC}, p_{DD})$, and it is a cooperative Nash strategy if and only if, the strategy entries satisfy the conditions,

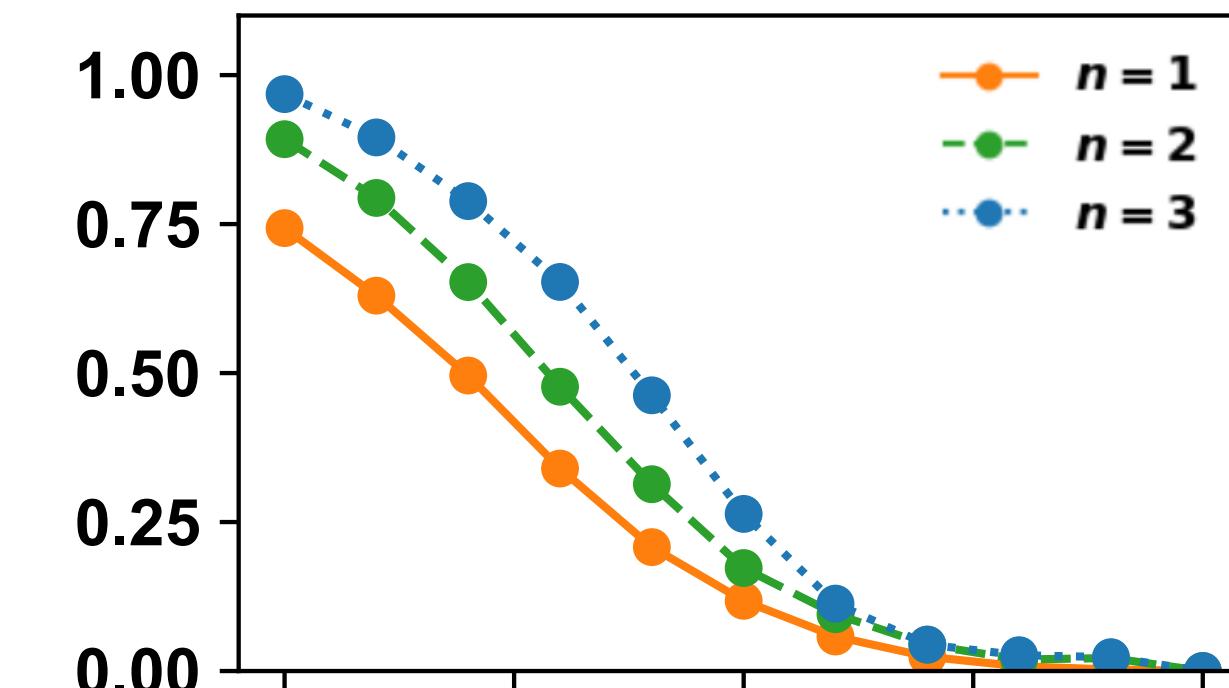
$$p_{CC} = 1, \quad \frac{p_{CD} + p_{DC}}{2} < 1 - \frac{1}{2} \cdot \frac{c}{b} \quad \text{and} \quad p_{DD} \leq 1 - \frac{c}{b}.$$

$n = 3$

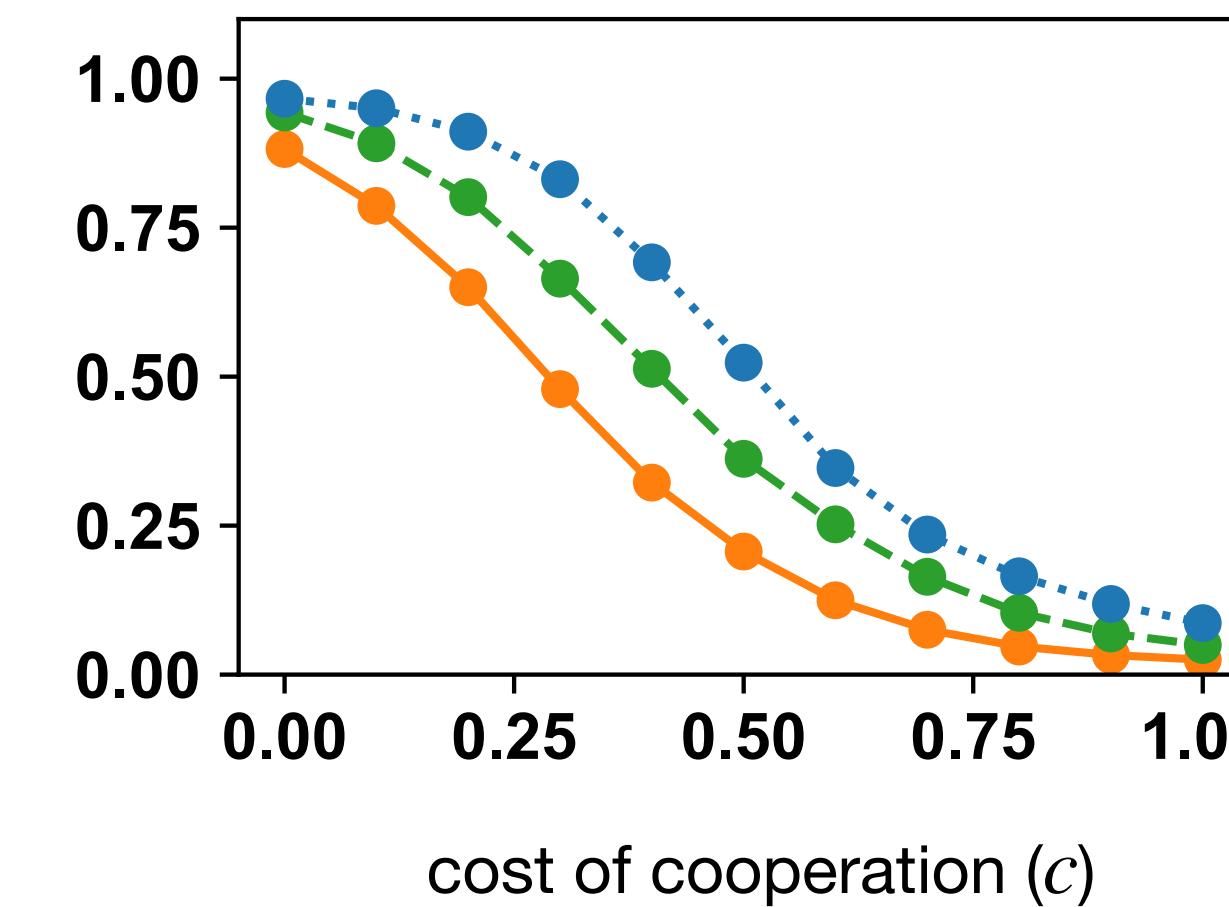
Theorem. A reactive-3 strategy is defined by the vector $\mathbf{p} = (p_{CCC}, p_{CCD}, p_{CDC}, p_{CDD}, p_{DCC}, p_{DCD}, p_{DDC}, p_{DDD})$, and it is a cooperative Nash strategy, if and only if the strategy entries satisfy the conditions,

$$\begin{aligned} p_{CCC} &= 1 \\ \frac{p_{CDC} + p_{DCD}}{2} &\leq 1 - \frac{1}{2} \cdot \frac{c}{b} \\ \frac{p_{CCD} + p_{CDC} + p_{DCC}}{3} &\leq 1 - \frac{1}{3} \cdot \frac{c}{b} \\ \frac{p_{CDD} + p_{DCD} + p_{DDC}}{3} &\leq 1 - \frac{2}{3} \cdot \frac{c}{b} \\ \frac{p_{CCD} + p_{CDD} + p_{DCC} + p_{DDC}}{4} &\leq 1 - \frac{1}{2} \cdot \frac{c}{b} \\ p_{DDD} &\leq 1 - \frac{c}{b} \end{aligned}$$

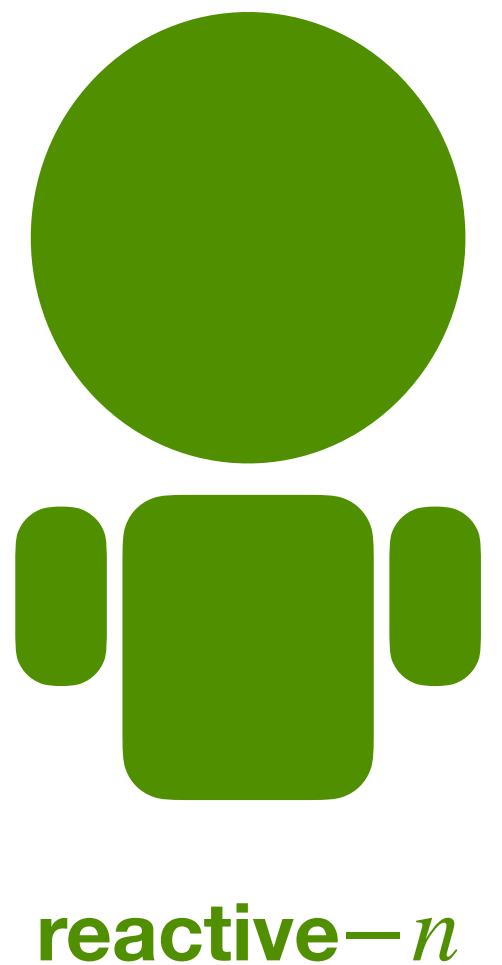
Abundance of cooperative Nash strategies



Average cooperation rate



3. Strategies in repeated interactions



- Develop an algorithm to verify whether a given reactive- n strategy is Nash
- Characterize cooperative & defective Nash strategies for $n = 2$ and $n = 3$
- Show that longer memory increases the average cooperation rate

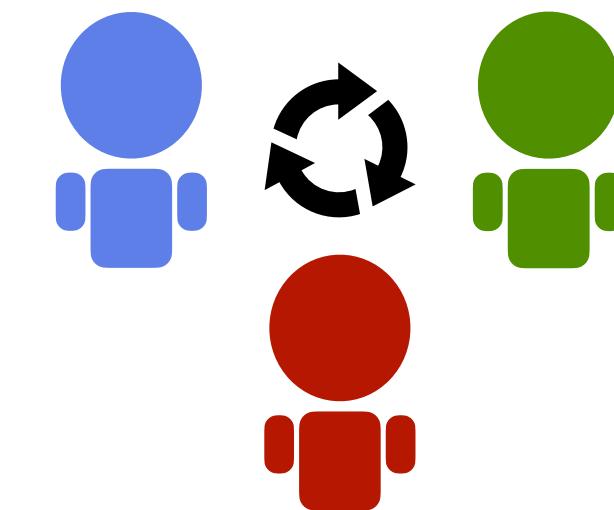
Current models on direct reciprocity make strong assumptions. Can we explore their impact?

What kinds of cognitive capacities are required for reciprocal altruism?

- [1] Reinforcement learning produces dominant strategies for the iterated prisoner's dilemma. <https://doi.org/10.1371/journal.pone.0188046>
- [2] Evolution reinforces cooperation with the emergence of self-recognition mechanisms. <https://doi.org/10.1371/journal.pone.0204981>
- [3] Properties of Winning Iterated Prisoner's Dilemma Strategies. <https://arxiv.org/abs/2001.05911>
- [4] Evolution of reciprocity with limited payoff memory. arXiv:2311.02365
- [5] Conditional cooperation with longer memory. arXiv:2402.02437

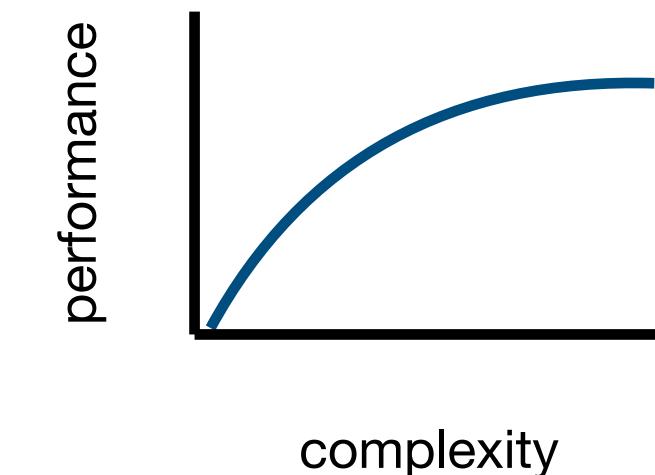
Future Research

1. Multi-player games / Multi agent learning

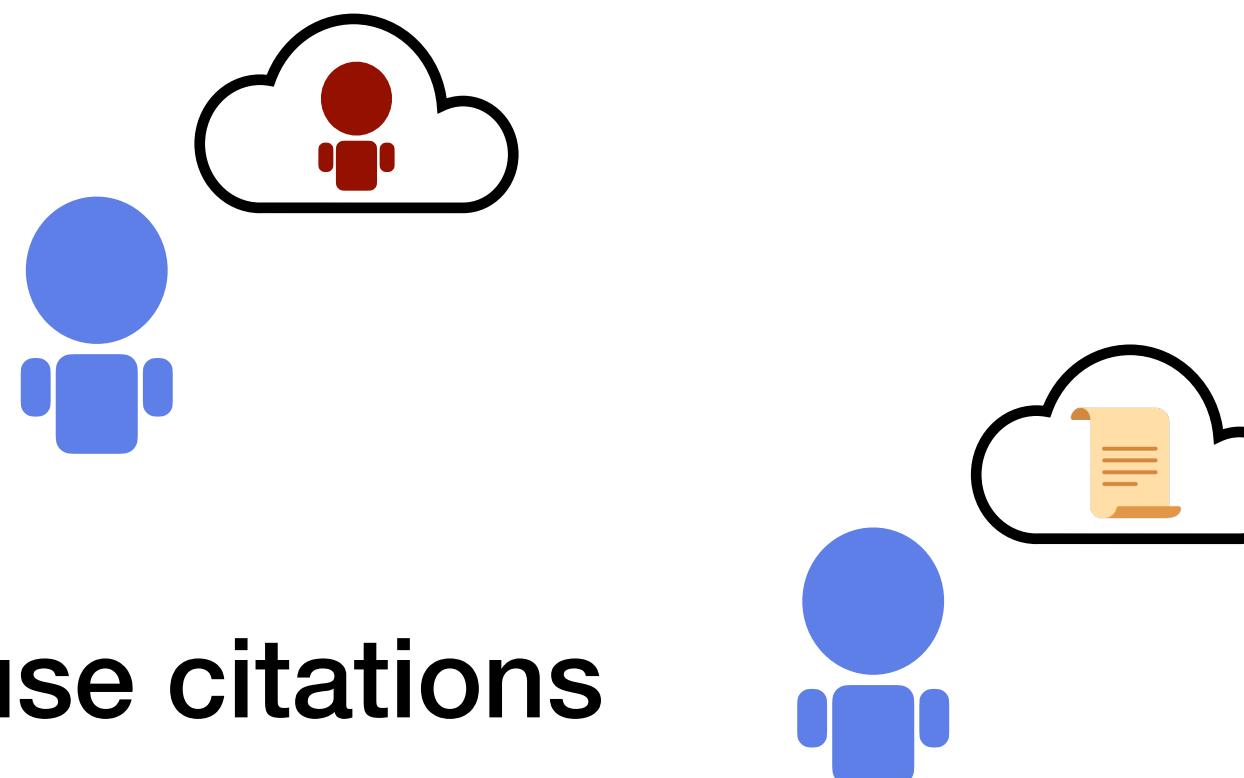


2. The benefits of increasing complexity

- Memory
- Finite state automata states

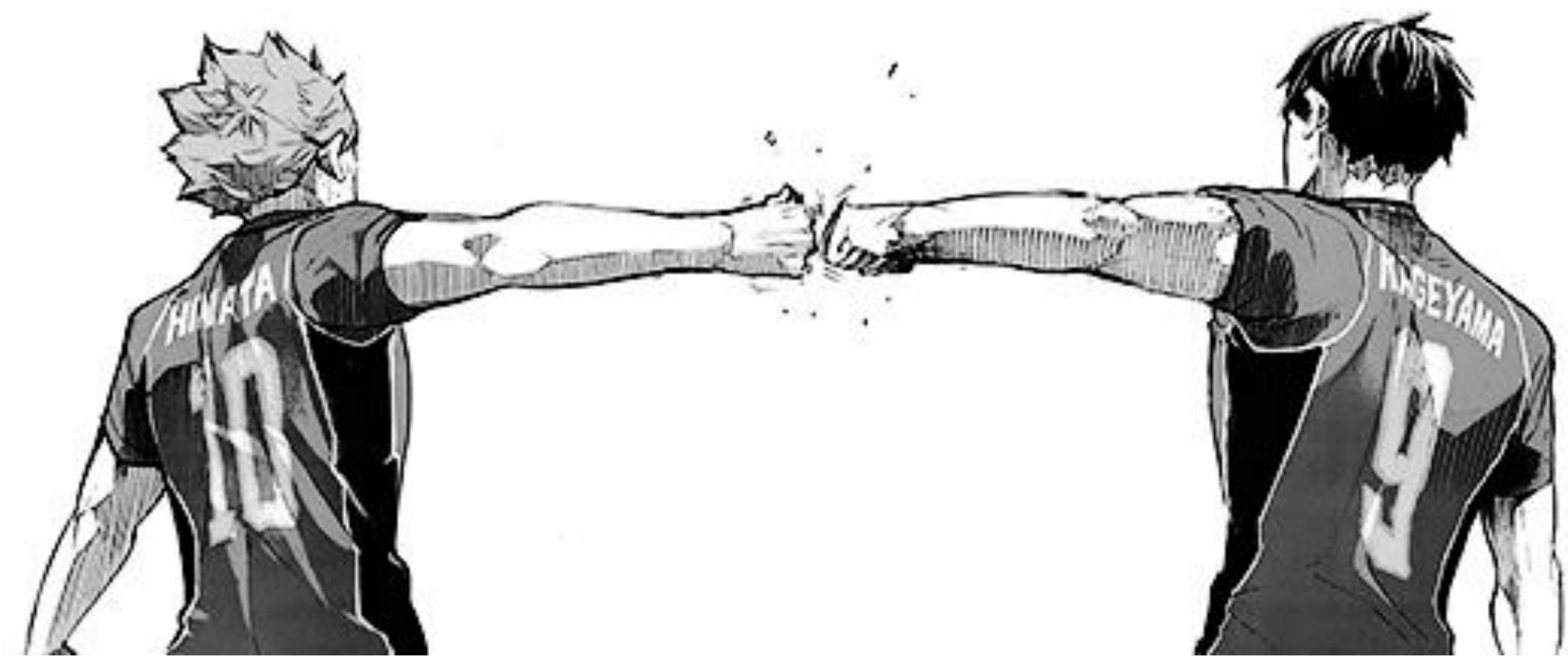


3. Strategy Inference



4. Explore how authors use citations

Future Research



Theoretical frameworks

Computational methodologies

Future Research

Why R-CCS?



**RIKEN R-CCS
Software Center**

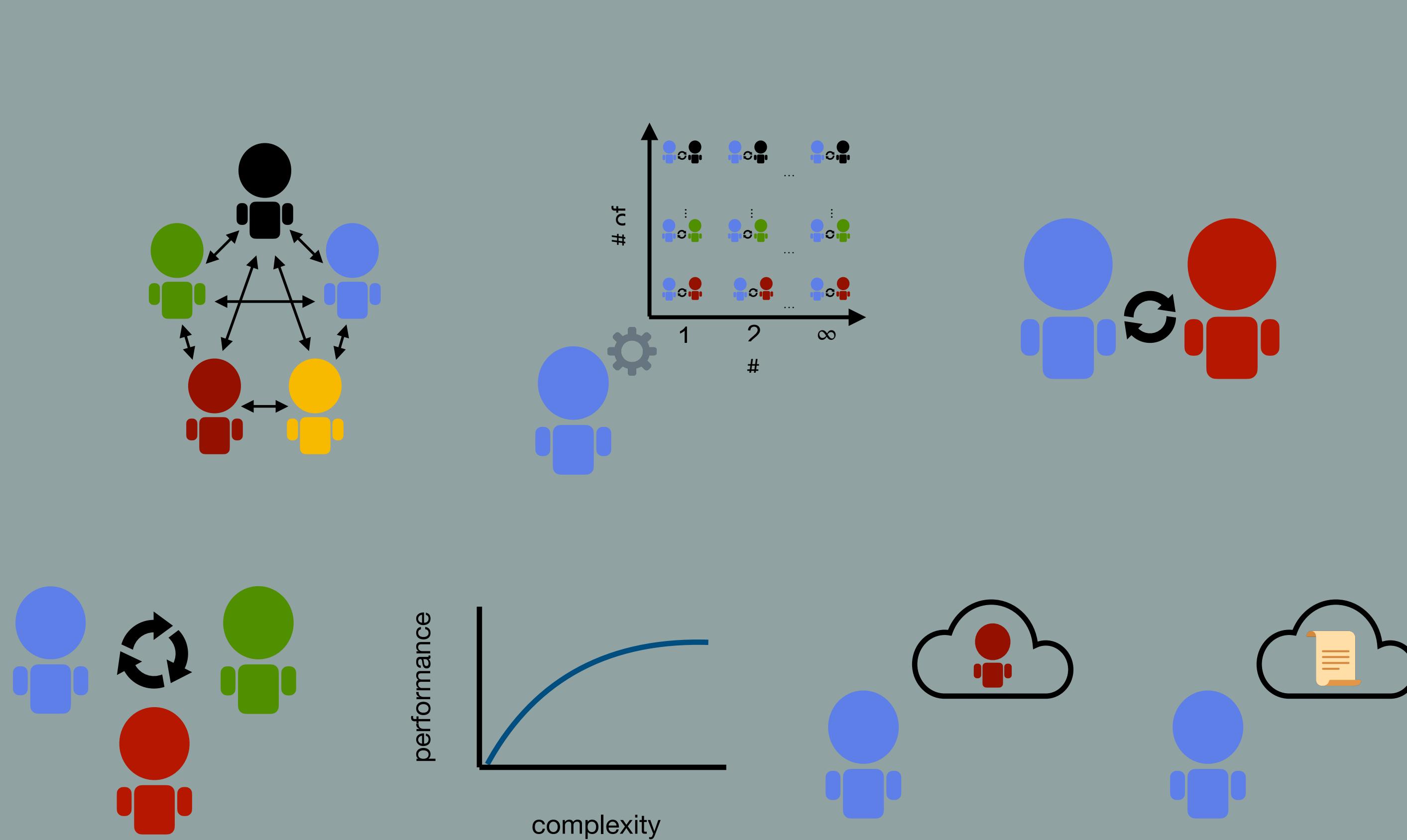
OACIS



Yohsuke Murase, RIKEN Center for Computational Science
Hisashi Ohtsuki, The Graduate University for Advanced Studies
Michihiro Kandori, The University of Tokyo
Akihiko Matsui, University of Tokyo
Masahiko Ueda, Yamaguchi University
Isamu Okada, Soka University
Nobuhiro Mifune, Kochi University of Technology

Career Goals

1. Firmly established in my field as a computational social scientist
2. Strong record of publications
3. International scientific network
4. Professor in computer science department



**Thank you for
your attention!**

Collaborators

- Christian Hilbe
- Vincent Knight
- Marc Harper
- Martin Jones
- George Koutsovoulos
- Owen Campbell
- Alex McAvoy
- Ethan Akin
- Martin Nowak



Nikoleta-v3



@NikoletaGlyn



<http://nikoleta-v3.github.io>