Limited information and the effects on the evolution of cooperation

Nikoleta E. Glynatsi

AMETHYST 2024

CARDIFF UNIVERSITY

PRIFYSGOL CAERDYDD

RIKEN

COOPERATION

COOPERATION

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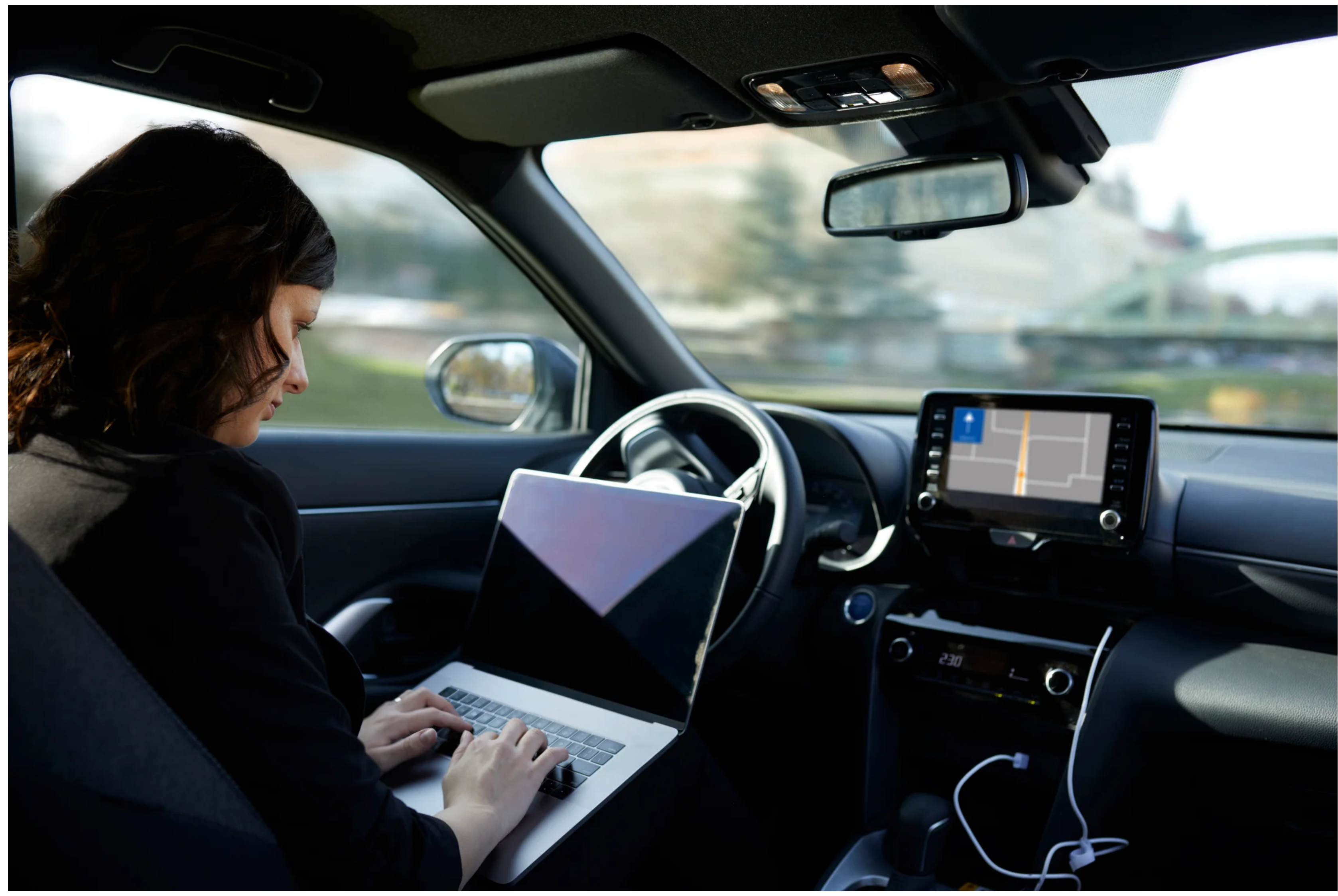


COOPERATION

PRISONER'S DILEMMA

$$
\begin{array}{cc}
 & \begin{array}{cc} C & D \end{array} \\
\begin{array}{c} C \\ D \end{array} & \begin{pmatrix} b-c & -c \\ b & 0 \end{pmatrix}
\end{array}
$$

$$b > c > 0$$

PRISONER'S DILEMMA

$$\begin{array}{cc} & \begin{array}{cc} C & D \end{array} \\ \begin{array}{c} C \\ D \end{array} & \begin{pmatrix} b-c & -c \\ b & \boxed{0} \end{pmatrix} \end{array}$$

$$b > c > 0$$

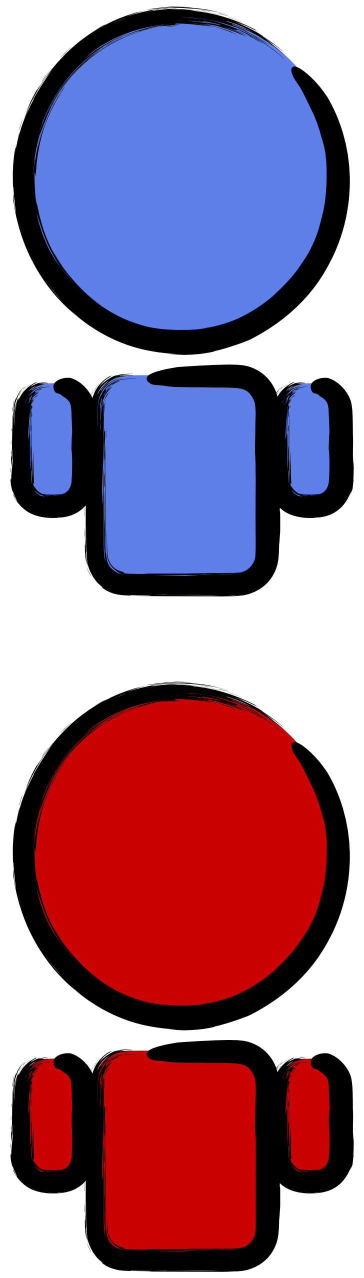
PRISONER'S DILEMMA

$$\begin{array}{cc} & \begin{array}{cc} C & D \end{array} \\ \begin{array}{c} C \\ D \end{array} & \begin{pmatrix} b-c & -c \\ b & \boxed{0} \end{pmatrix} \end{array}$$

Nash Equilibrium

$$b > c > 0$$

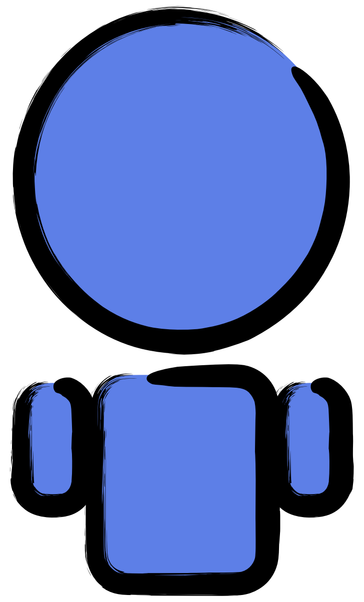
DIRECT RECIPROCITY



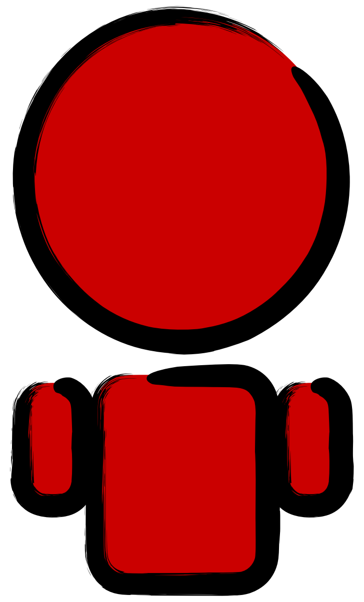
DIRECT RECIPROCITY

1

$$\begin{pmatrix} b-c & -c \\ b & 0 \end{pmatrix}$$



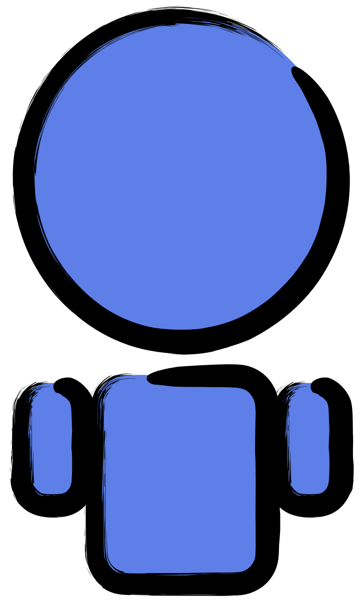
D



D

DIRECT RECIPROCITY

$$\begin{array}{cc} 1 & 2 \\ \begin{pmatrix} b-c & -c \\ b & 0 \end{pmatrix} & \begin{pmatrix} b-c & -c \\ b & 0 \end{pmatrix} \end{array}$$



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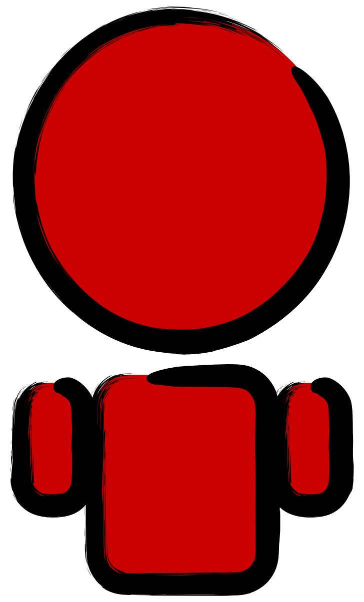
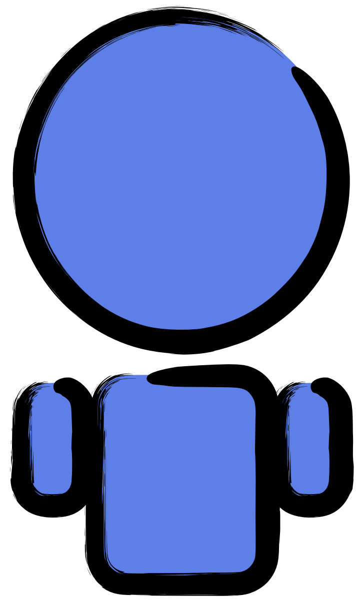


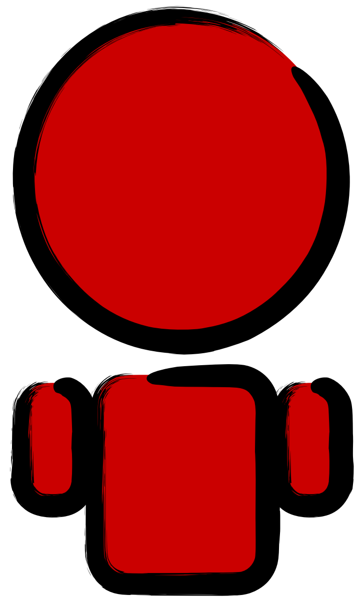
D

DIRECT RECIPROCITY

$$\begin{array}{cc} 1 & 2 \\ \begin{pmatrix} b-c & -c \\ b & 0 \end{pmatrix} & \begin{pmatrix} b-c & -c \\ b & 0 \end{pmatrix} \end{array}$$

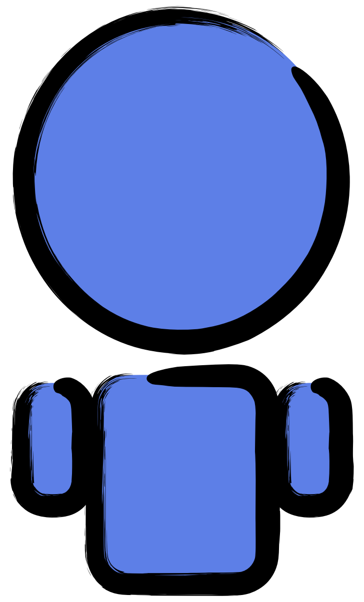
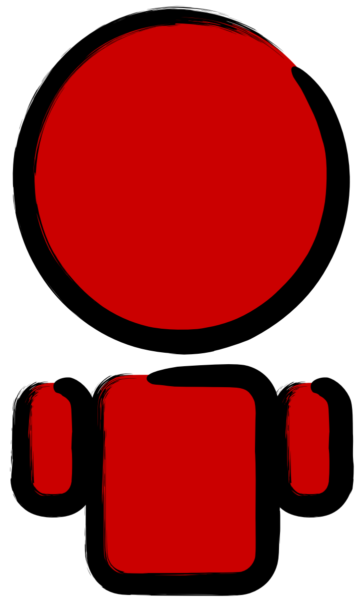


D C

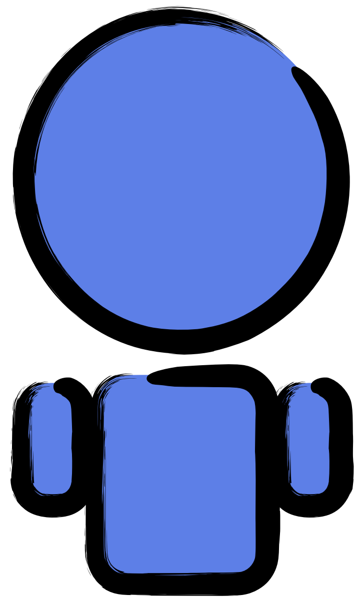
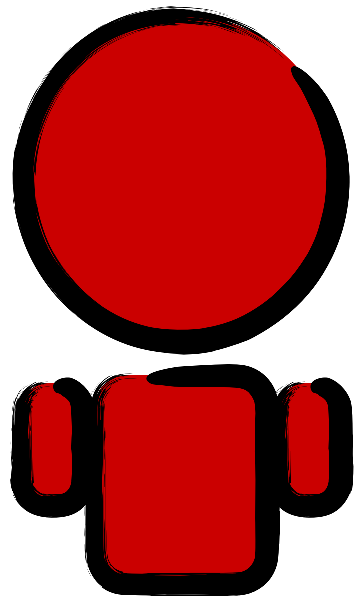


D D

DIRECT RECIPROCITY

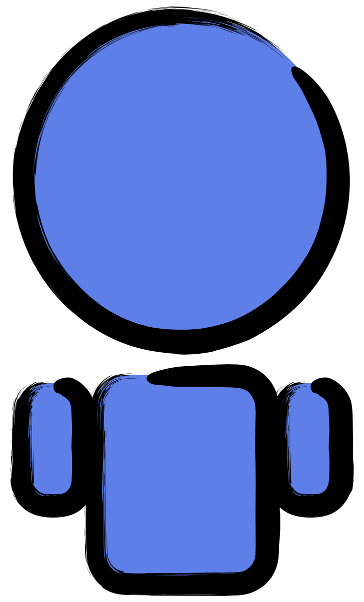
	1	2	3
	$\begin{pmatrix} b-c & -c \\ b & 0 \end{pmatrix}$	$\begin{pmatrix} b-c & -c \\ b & 0 \end{pmatrix}$	$\begin{pmatrix} b-c & -c \\ b & 0 \end{pmatrix}$
	D	C	
	D	D	

DIRECT RECIPROCITY

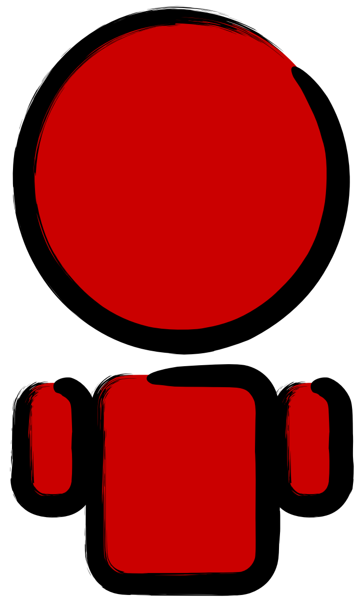
	1	2	3
	$\begin{pmatrix} b-c & -c \\ b & 0 \end{pmatrix}$	$\begin{pmatrix} b-c & -c \\ b & 0 \end{pmatrix}$	$\begin{pmatrix} b-c & -c \\ b & 0 \end{pmatrix}$
	D	C	C
	D	D	C

DIRECT RECIPROCITY

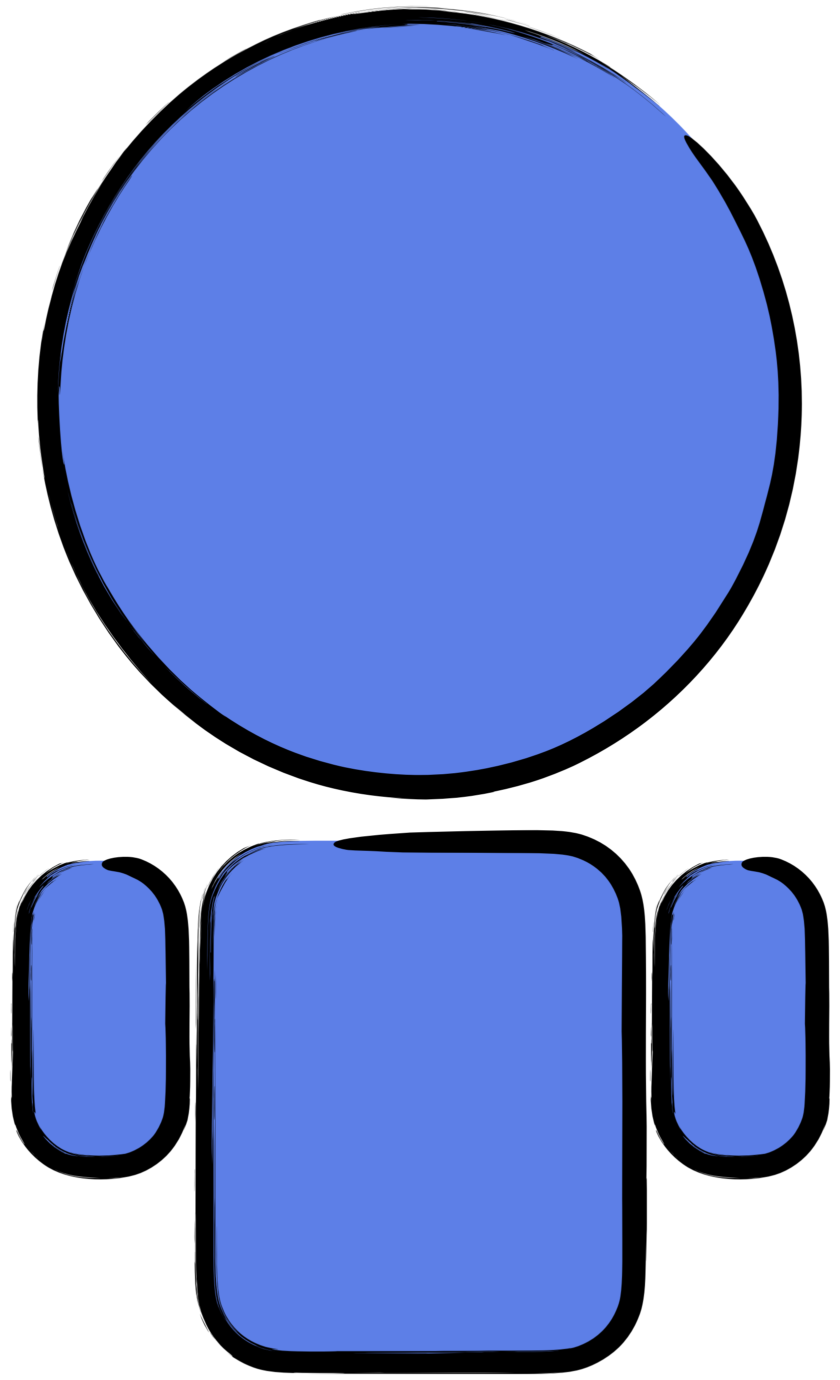
$$\begin{array}{ccccc} 1 & 2 & 3 & & n \\ \begin{pmatrix} b-c & -c \\ b & 0 \end{pmatrix} & \begin{pmatrix} b-c & -c \\ b & 0 \end{pmatrix} & \begin{pmatrix} b-c & -c \\ b & 0 \end{pmatrix} & \cdots & \begin{pmatrix} b-c & -c \\ b & 0 \end{pmatrix} \end{array}$$

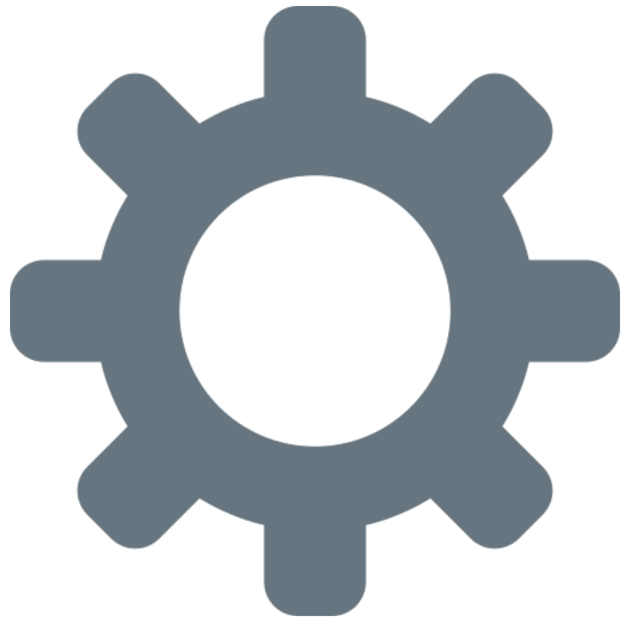


$$D \qquad C \qquad C \qquad \cdots \qquad C$$

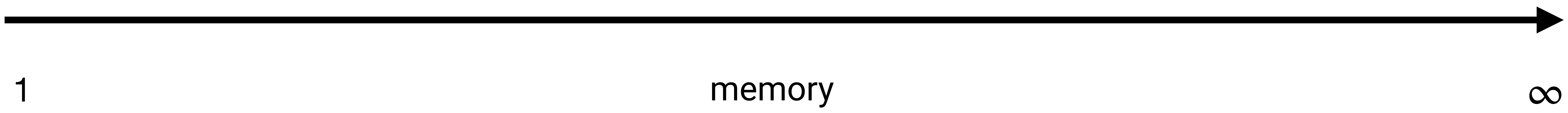


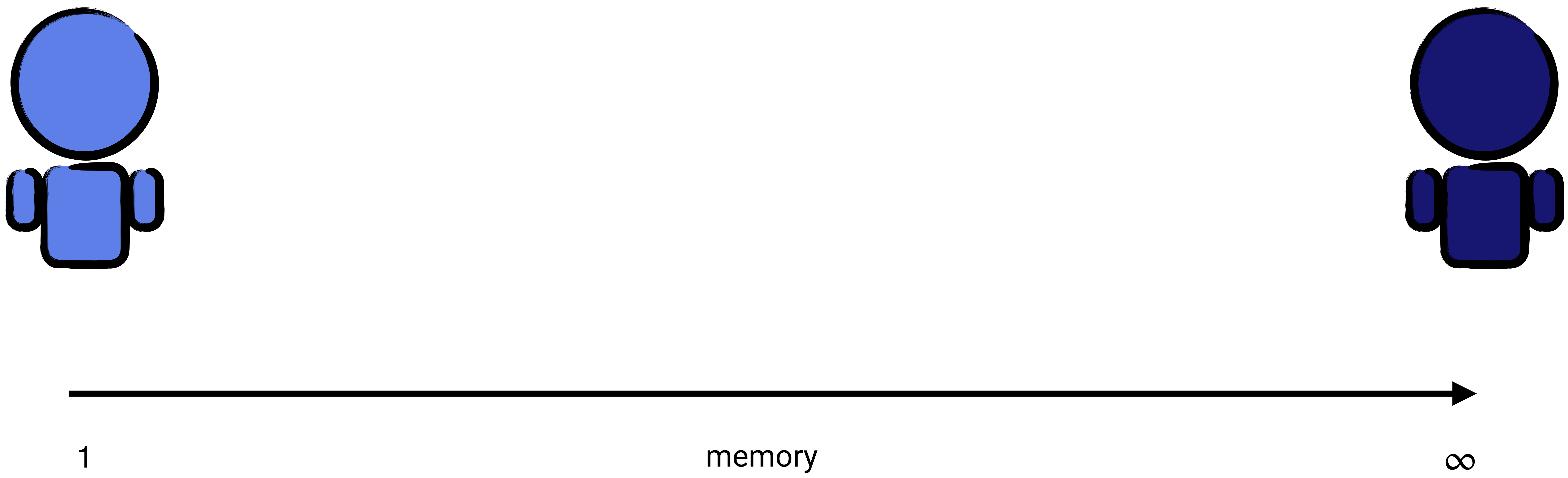
$$D \qquad D \qquad C \qquad \cdots \qquad C$$





remember &
process information


1
memory
∞


1
memory
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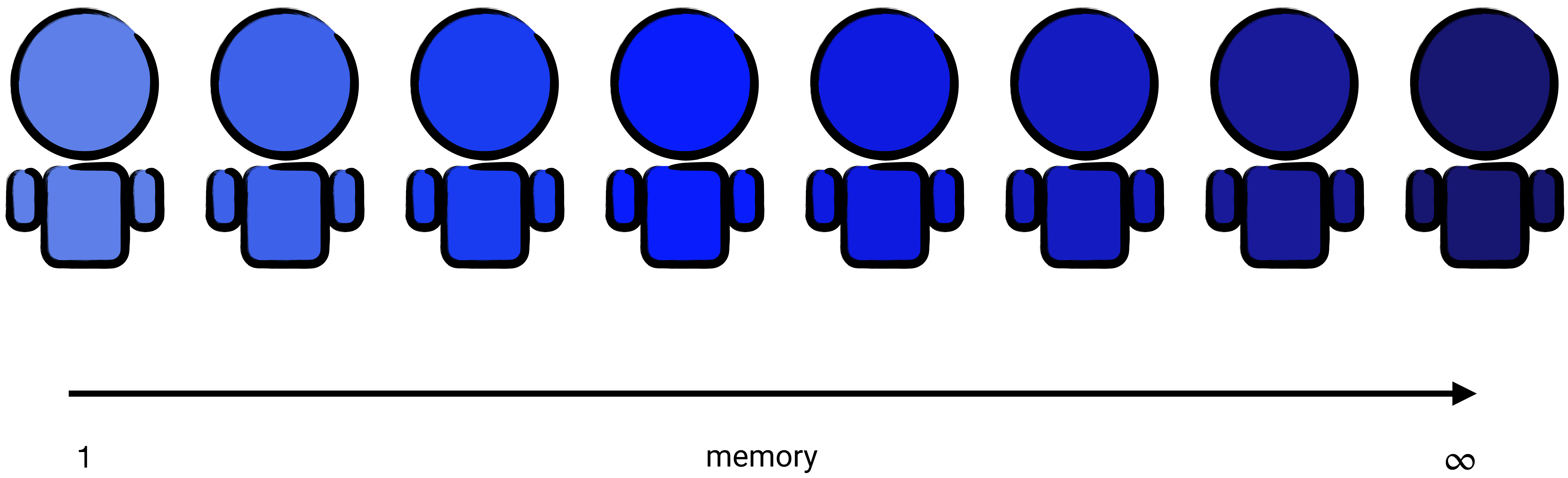
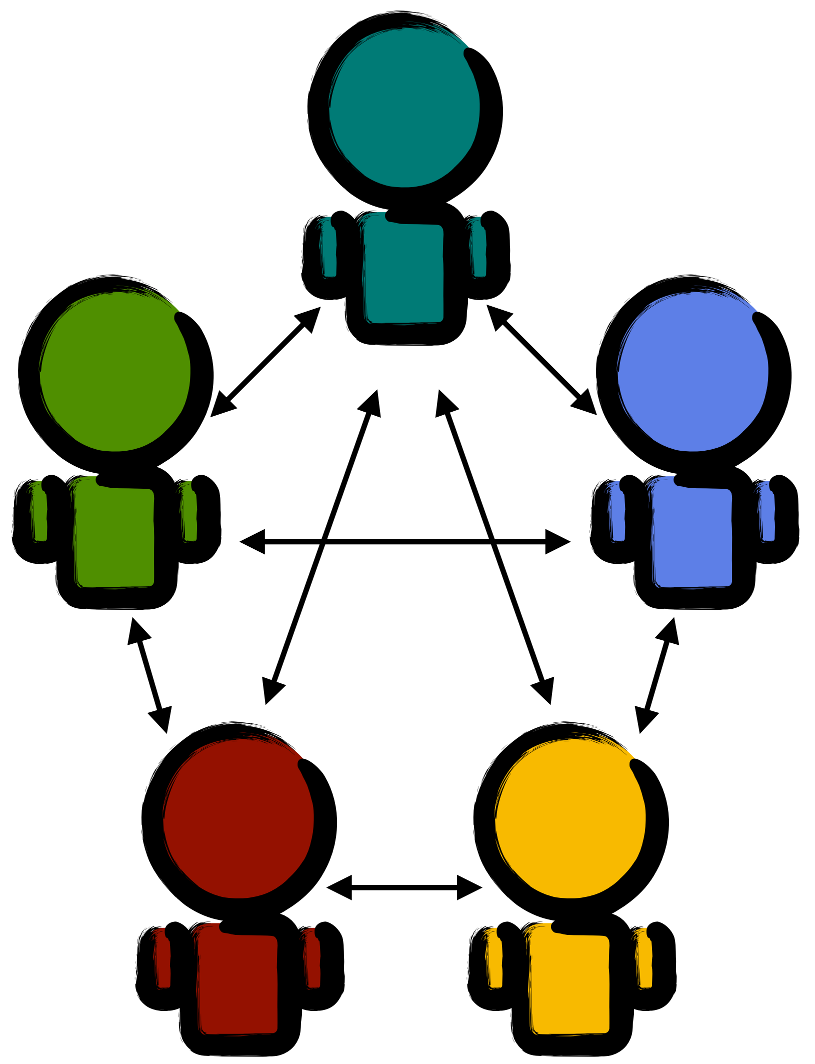
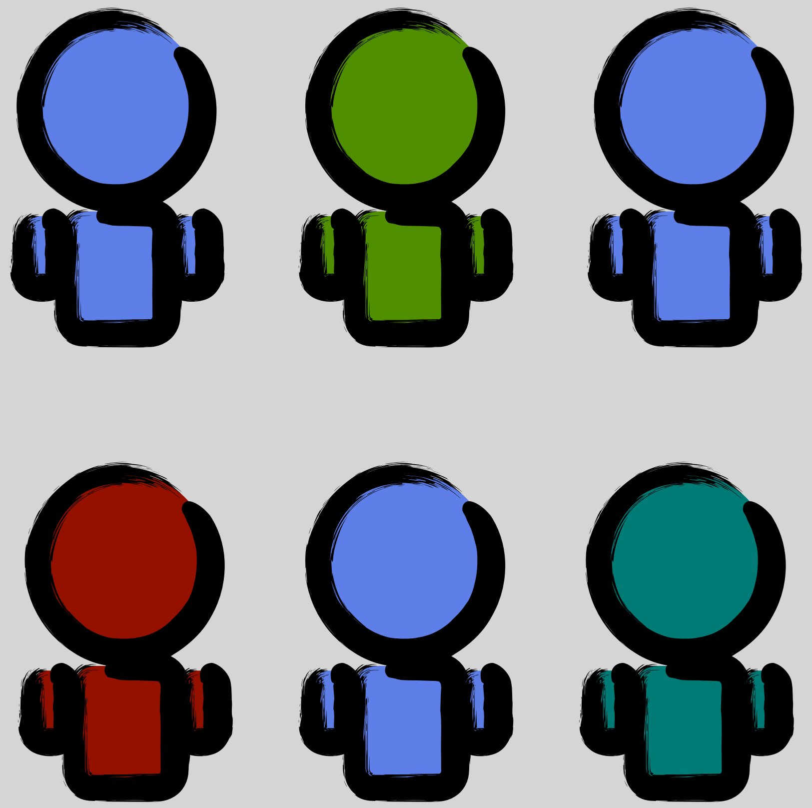


1
memory
∞

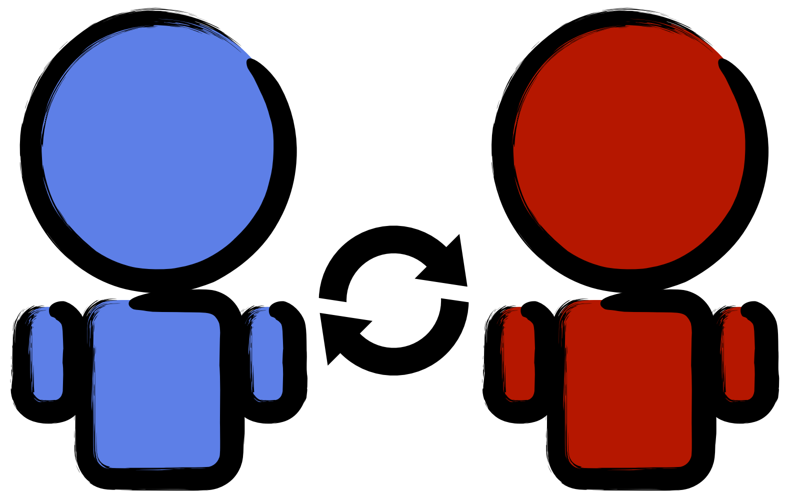
Strategies in computer tournaments



Learning in populations



Strategies in repeated interactions



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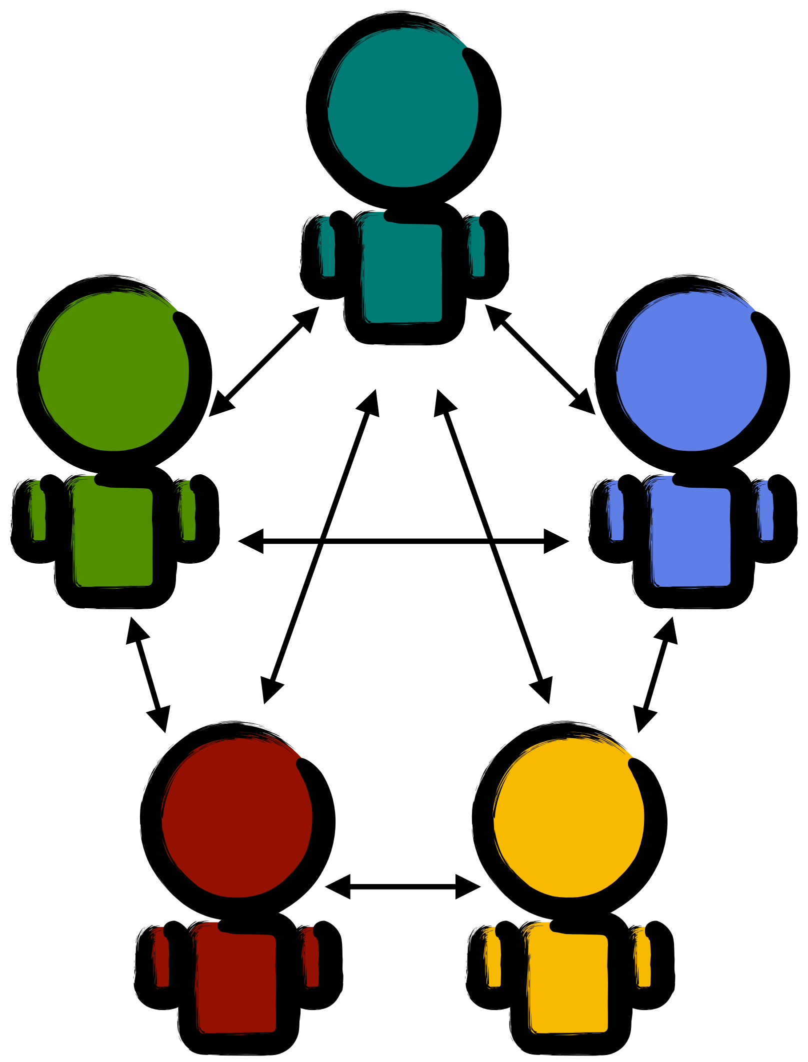

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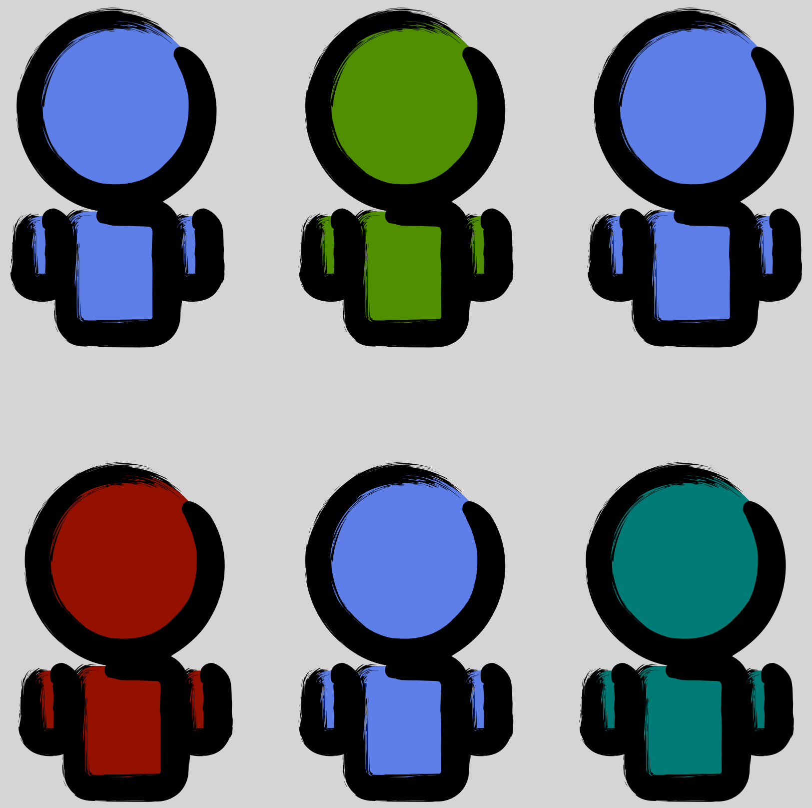

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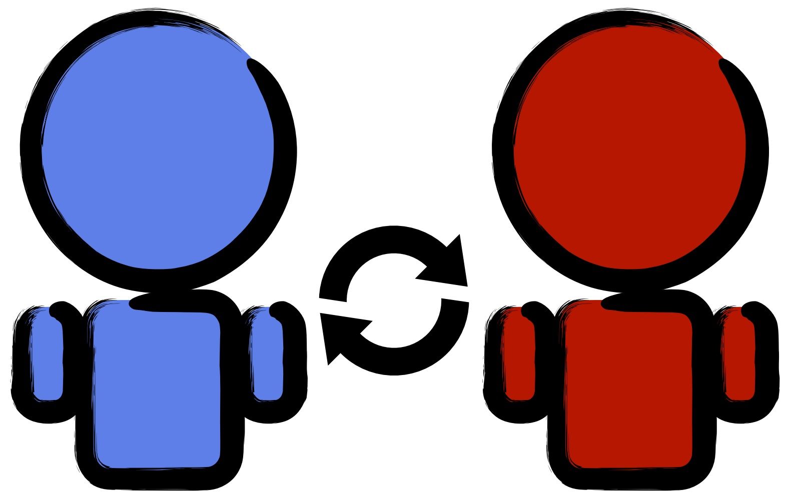
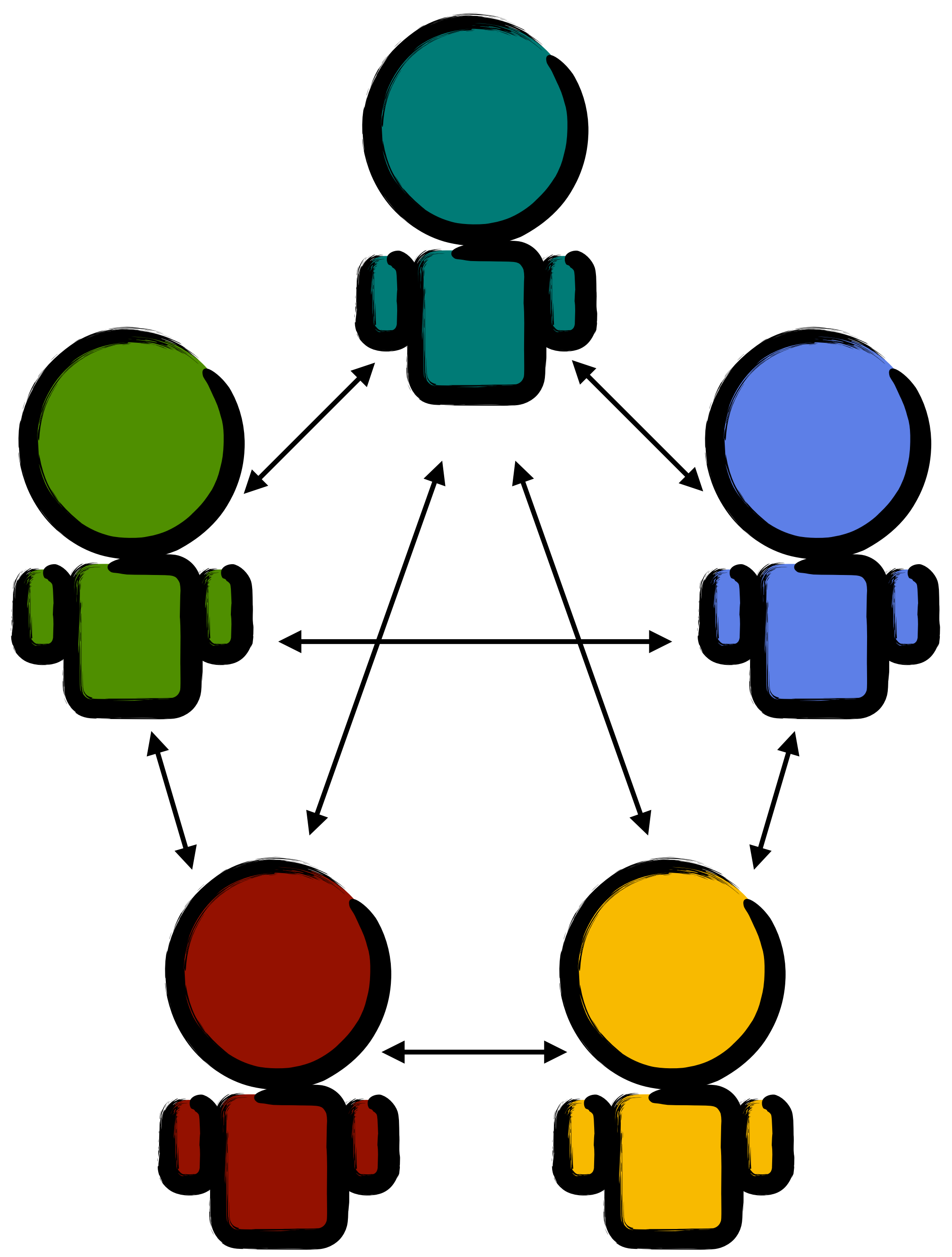


STRATEGIES IN COMPUTER TOURNAMENTS



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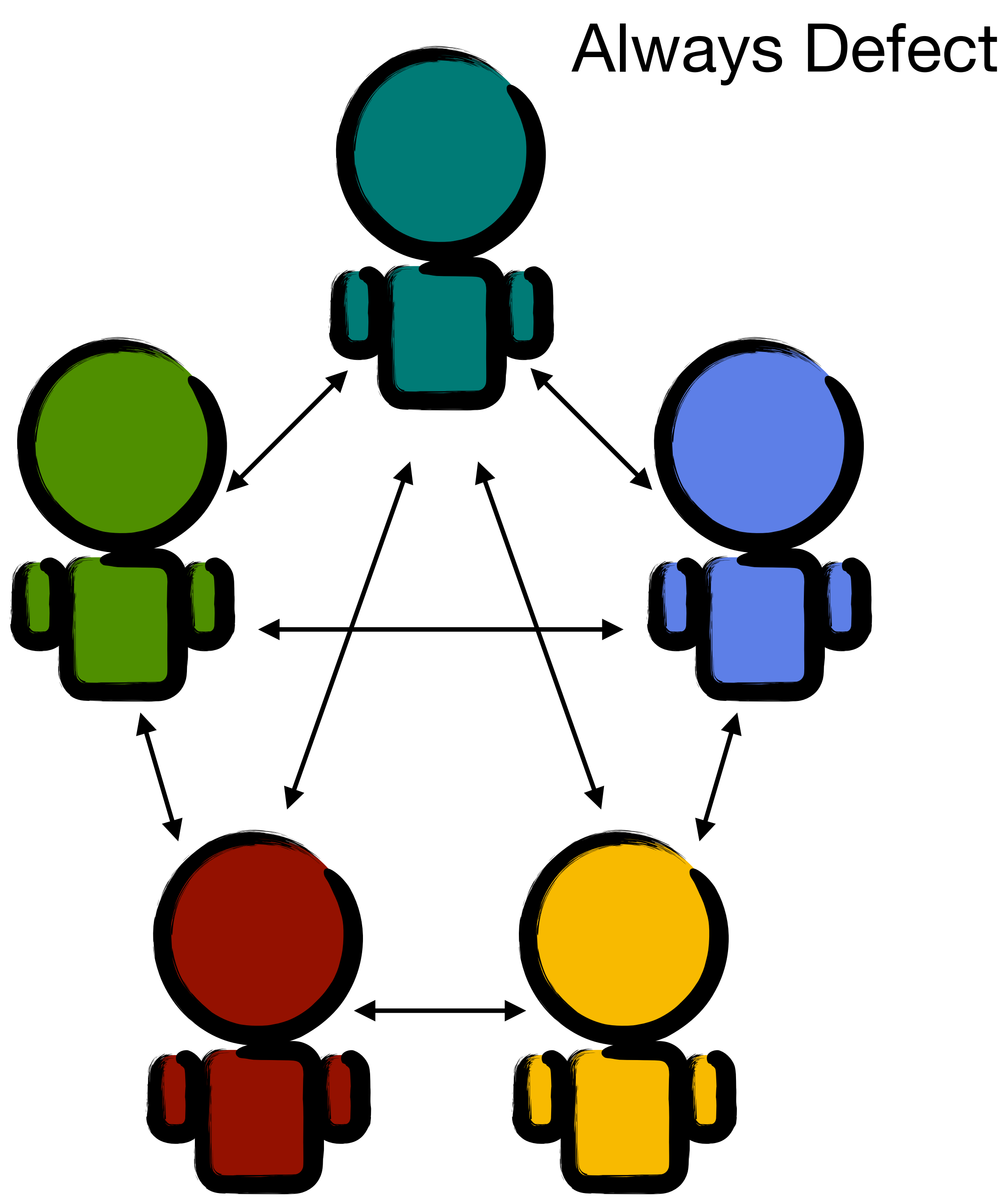

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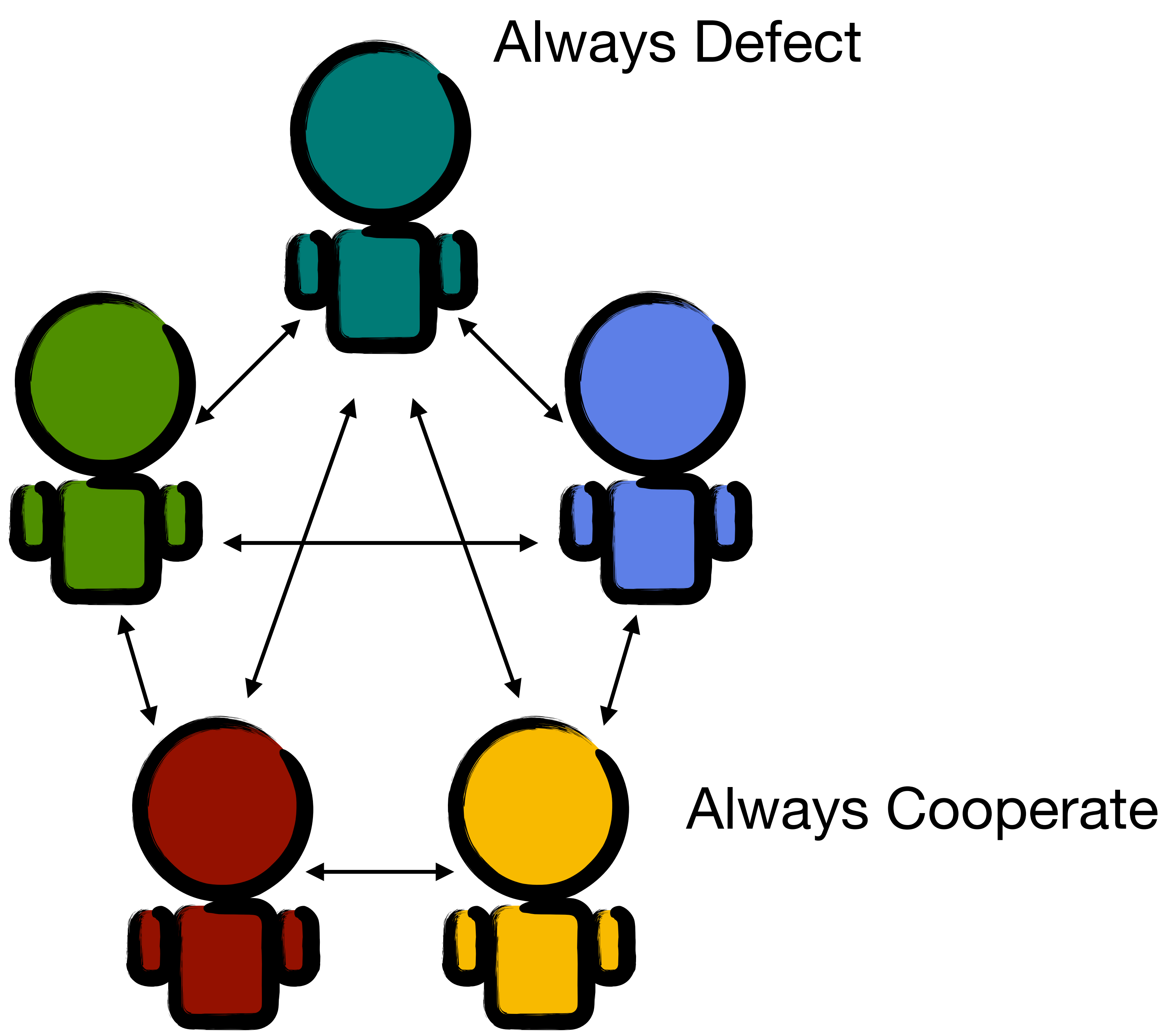

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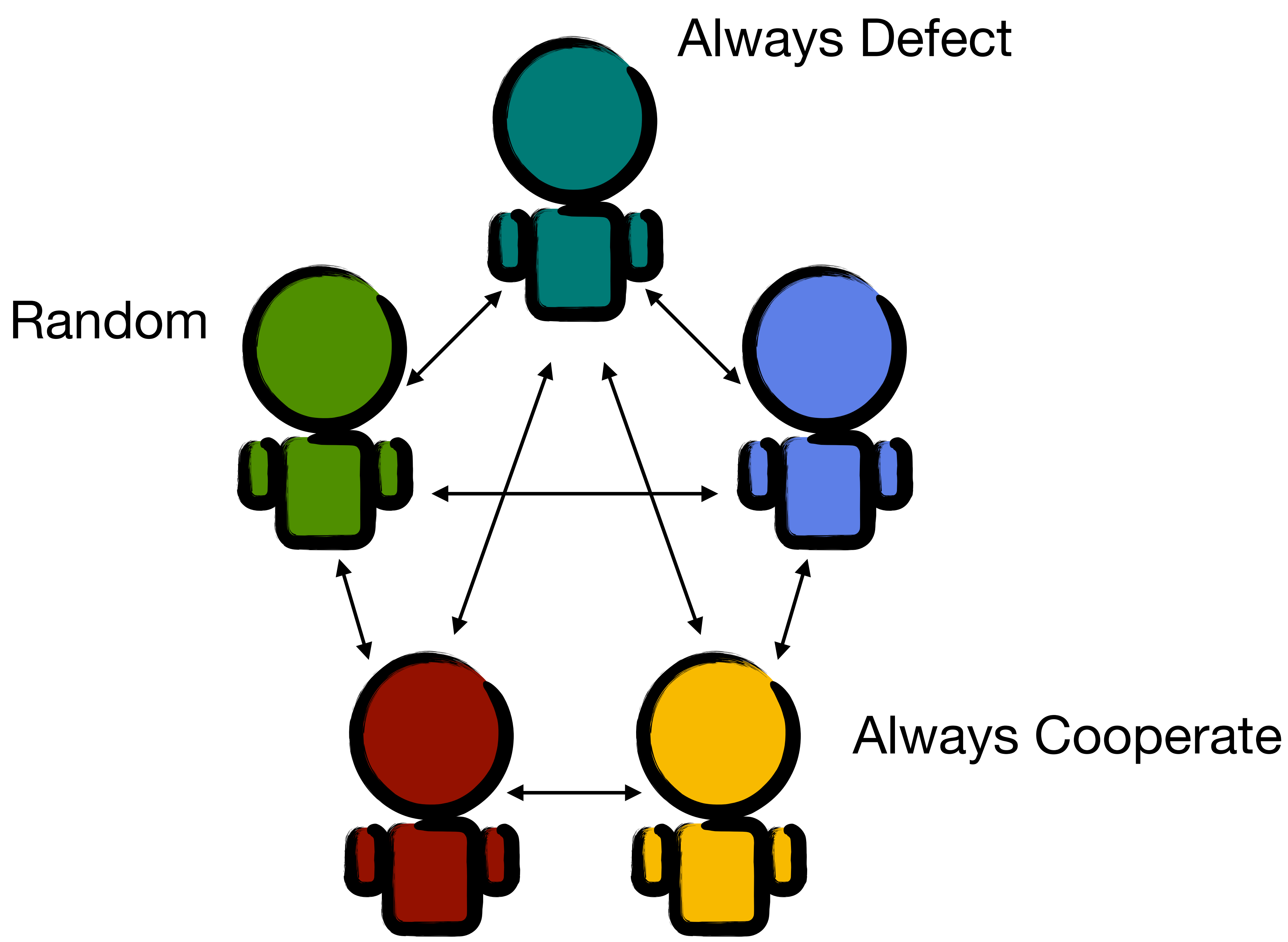

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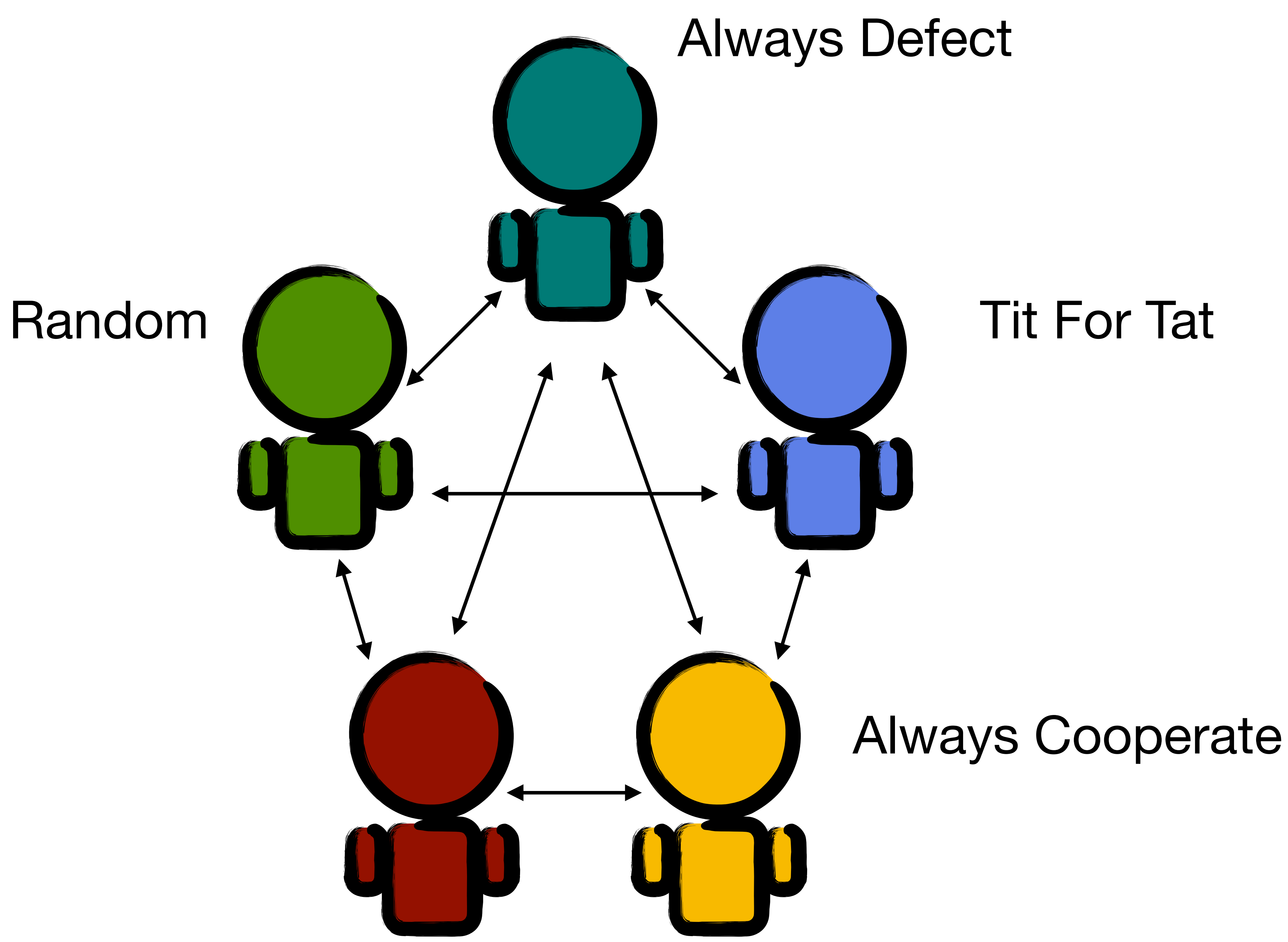

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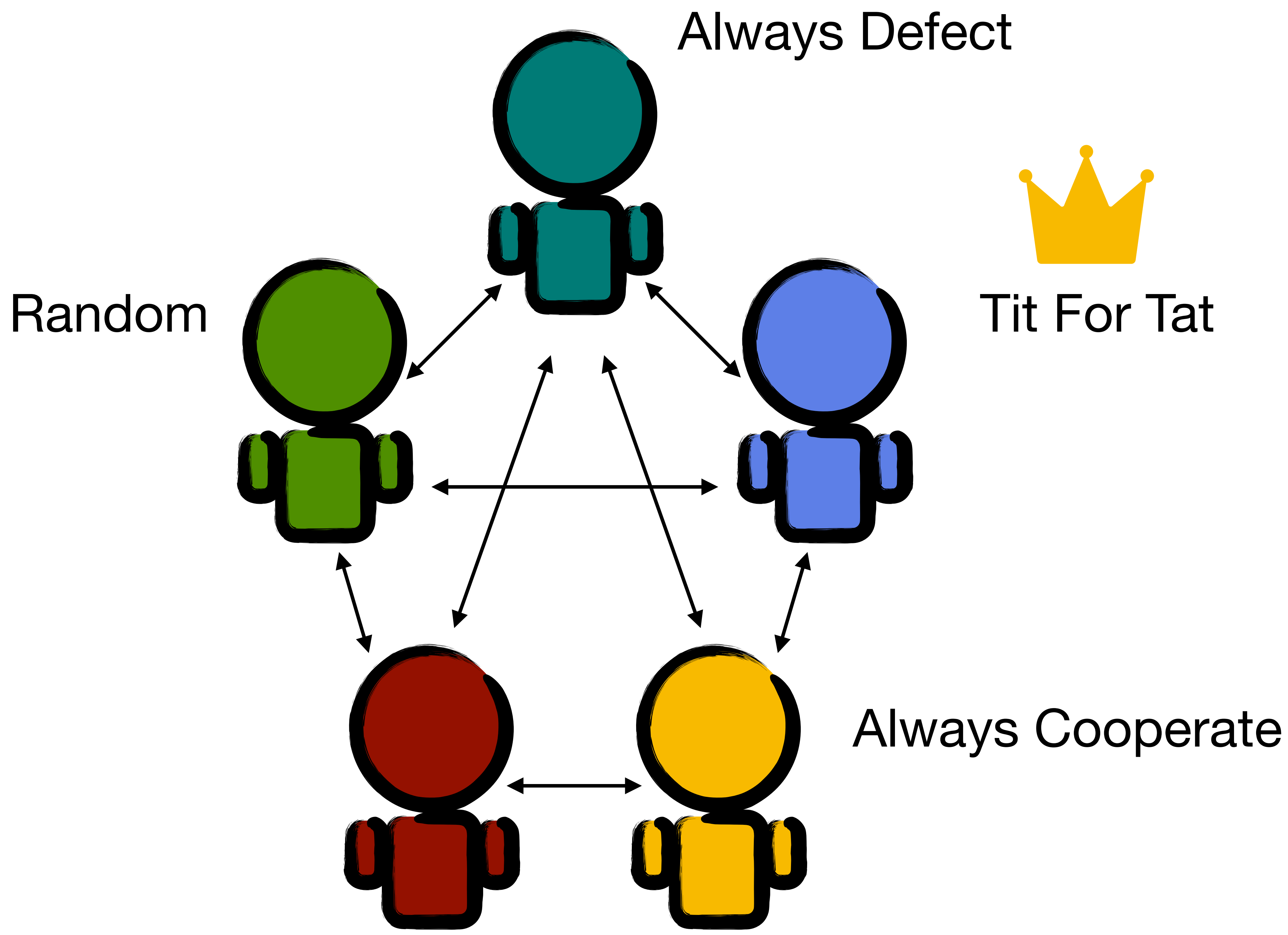

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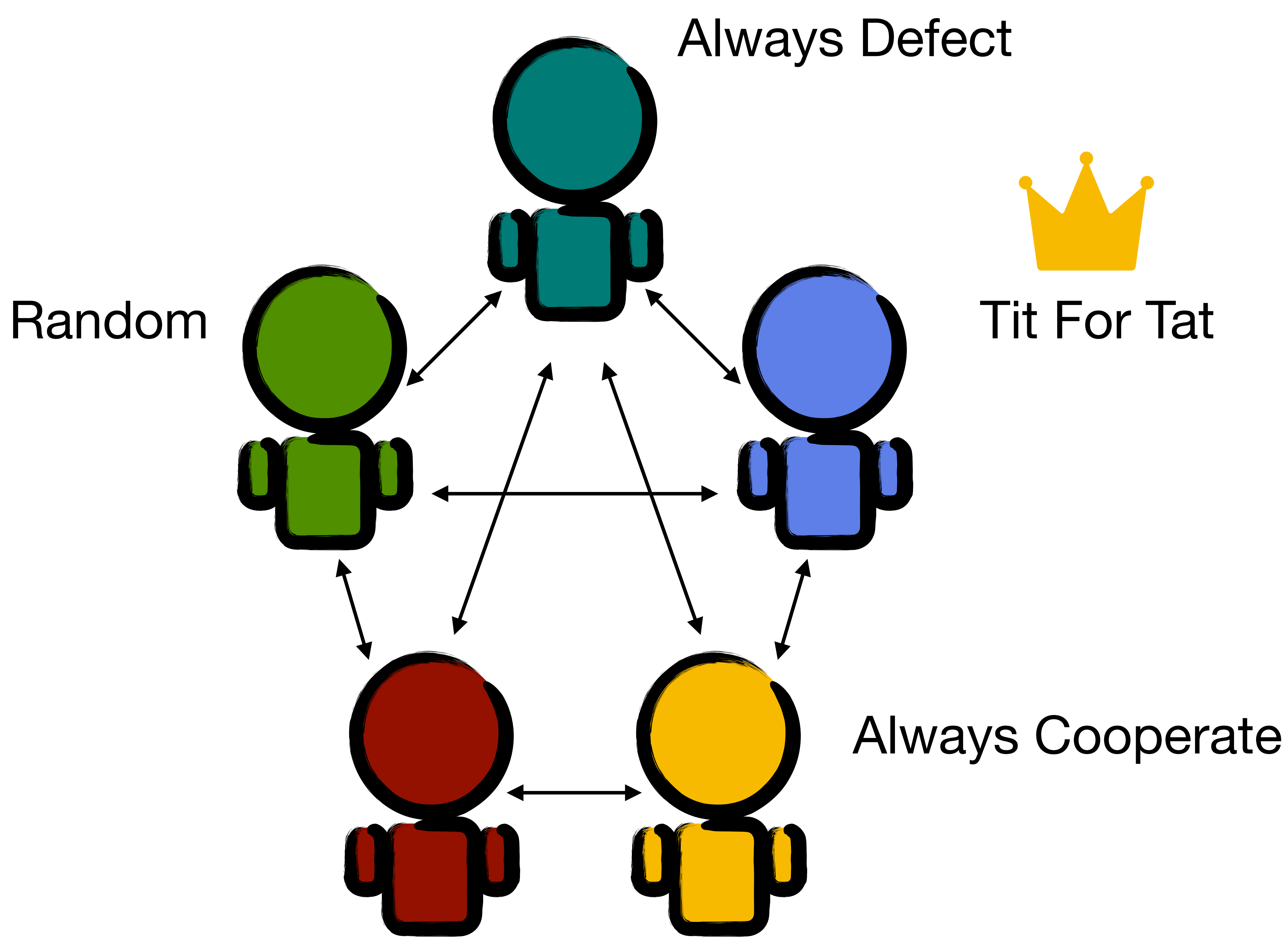
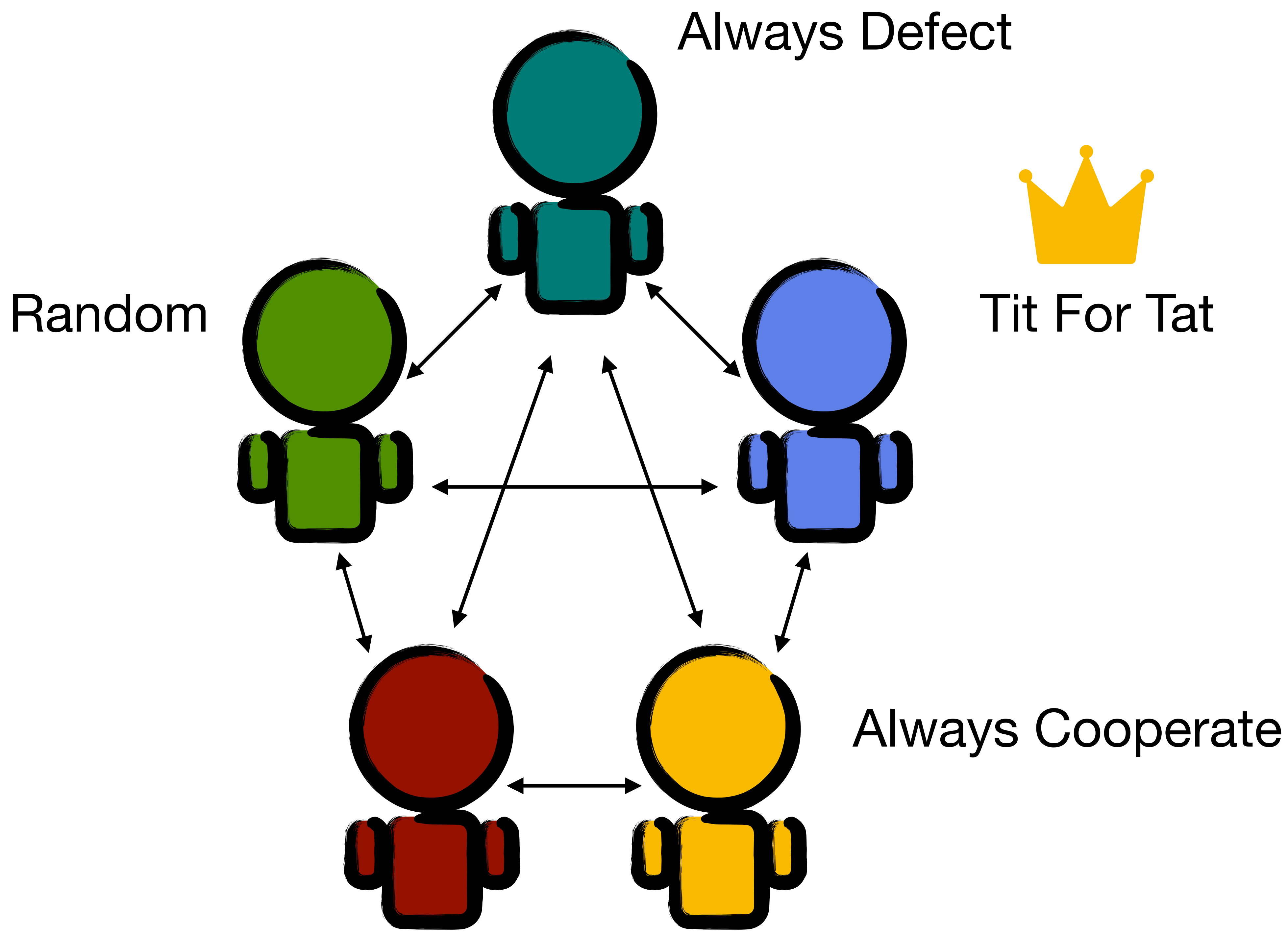


Most strategies are quite simple rules

STRATEGIES IN COMPUTER TOURNAMENTS



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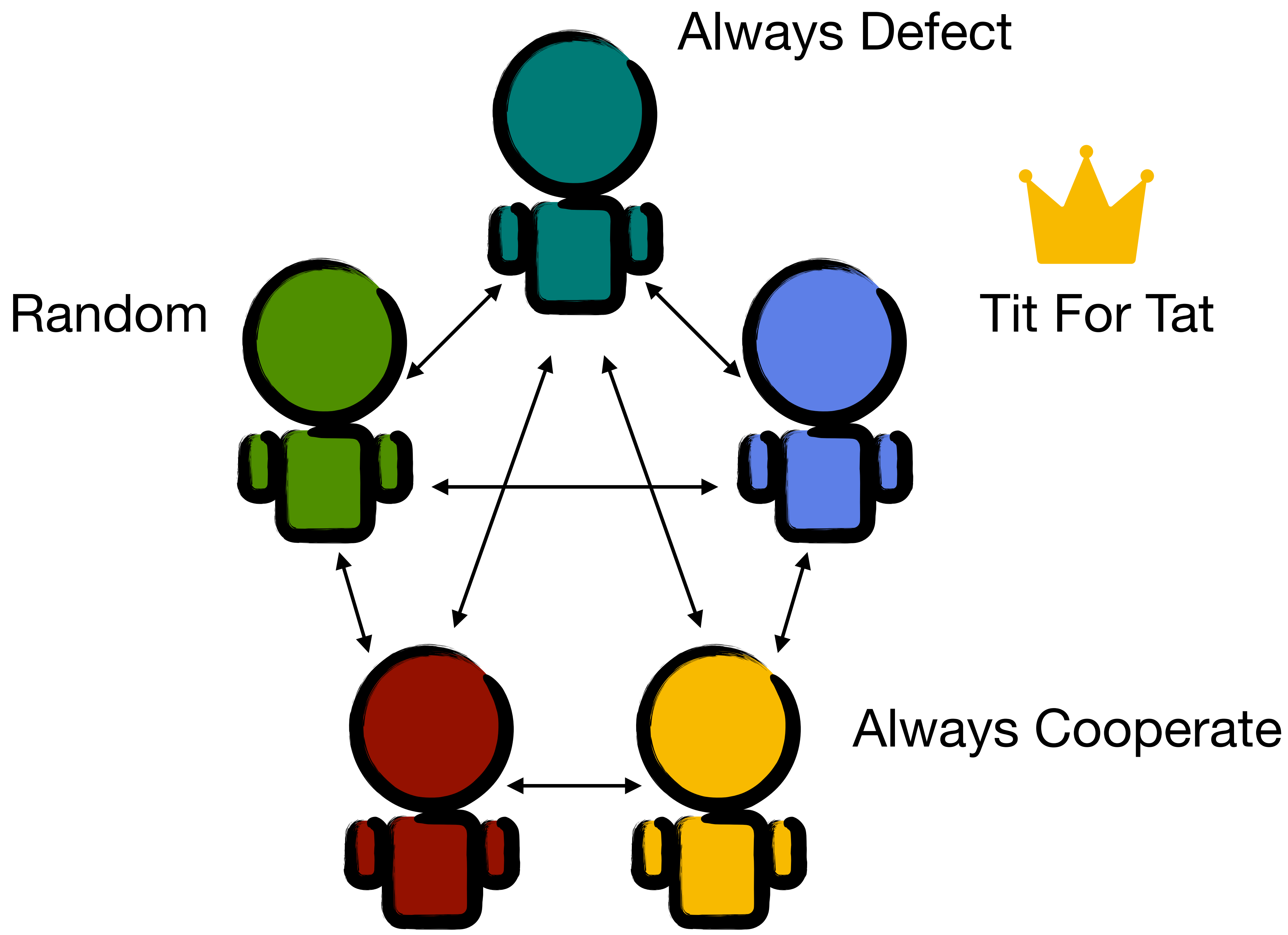
↓

Interpretability

STRATEGIES IN COMPUTER TOURNAMENTS



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Interpretability

Introduce complex strategies

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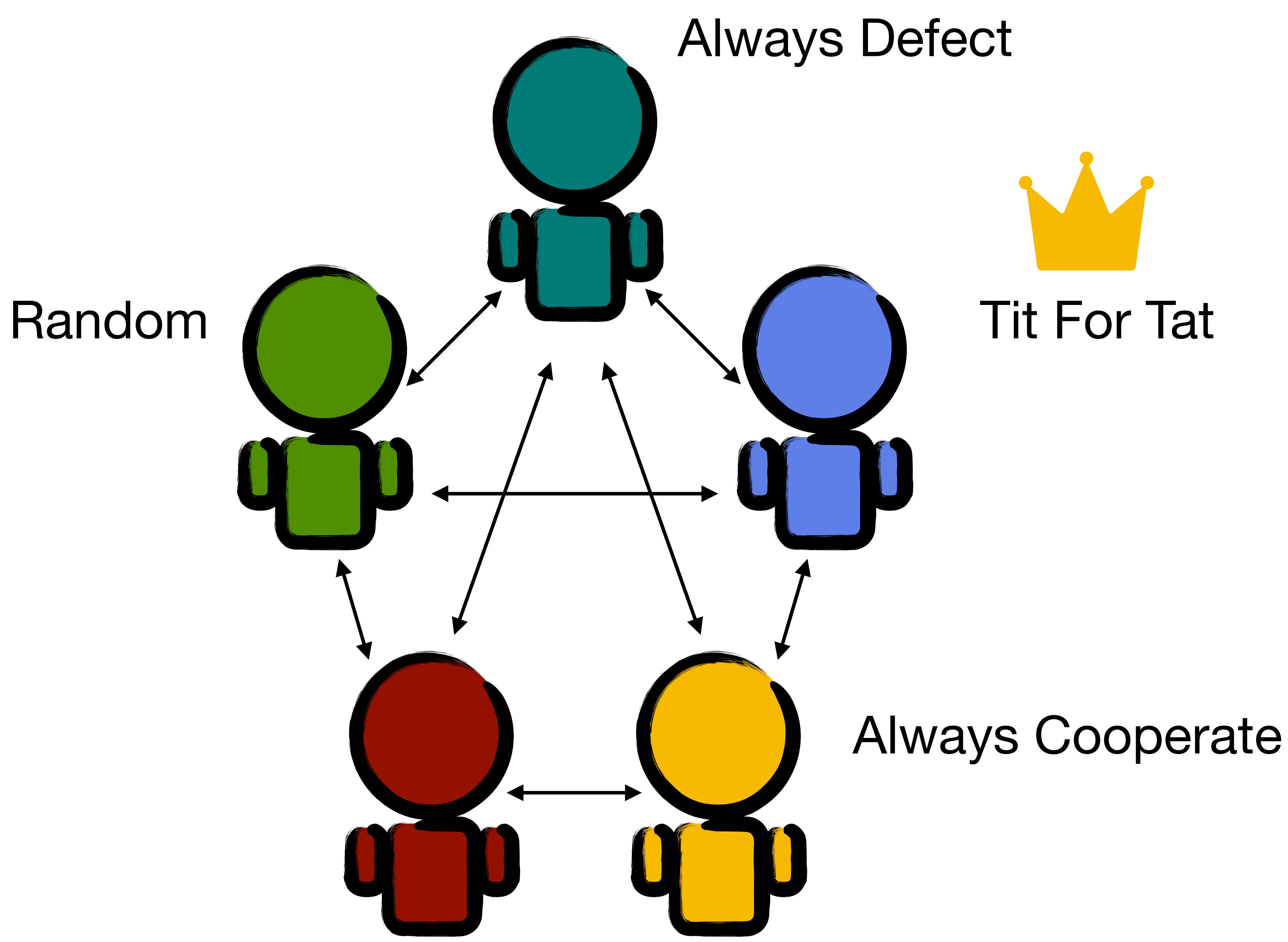


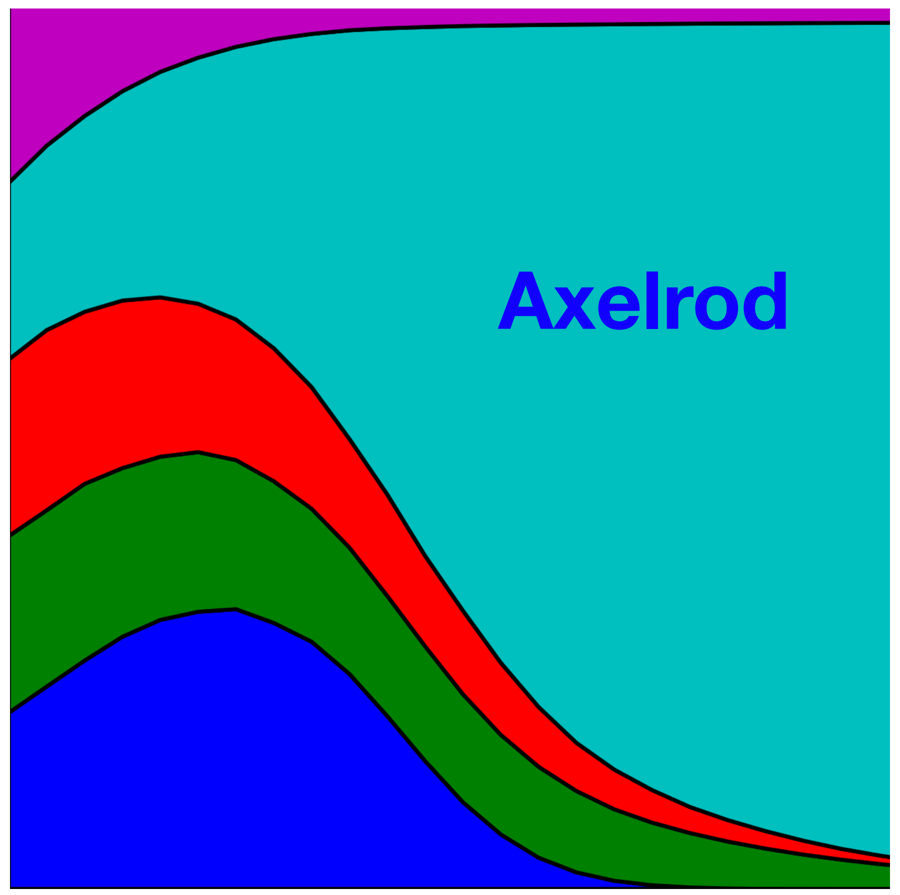
Most strategies are quite simple rules

Interpretability

Introduce complex strategies

Understand properties of them

STRATEGIES IN COMPUTER TOURNAMENTS



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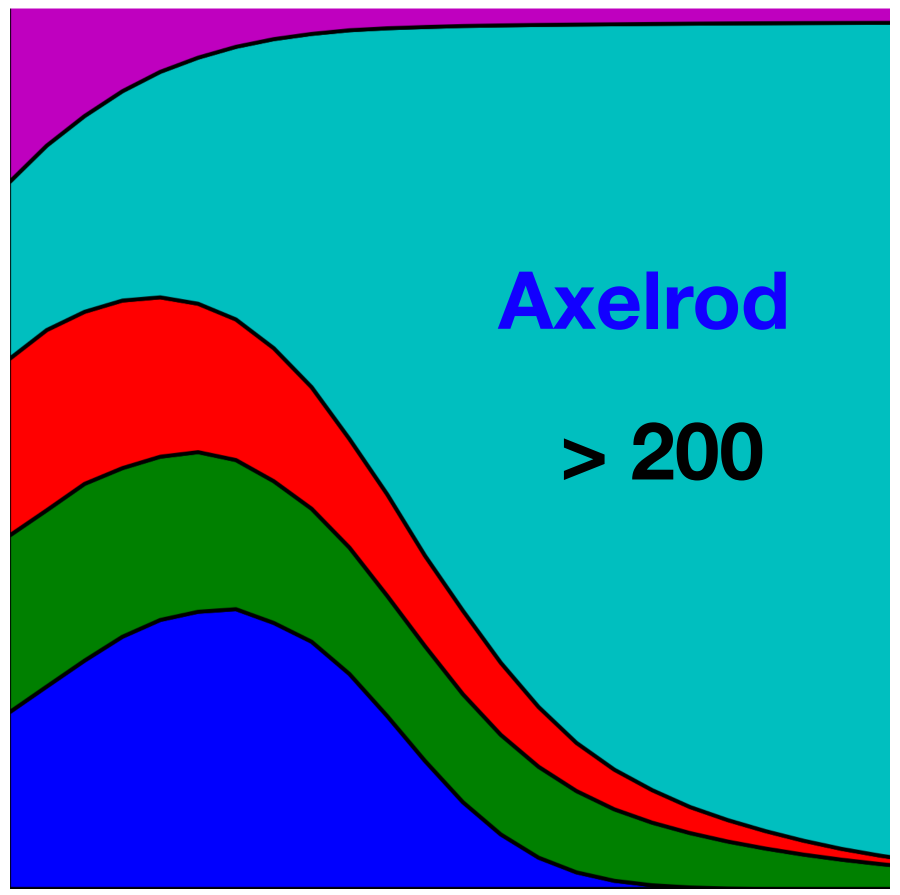

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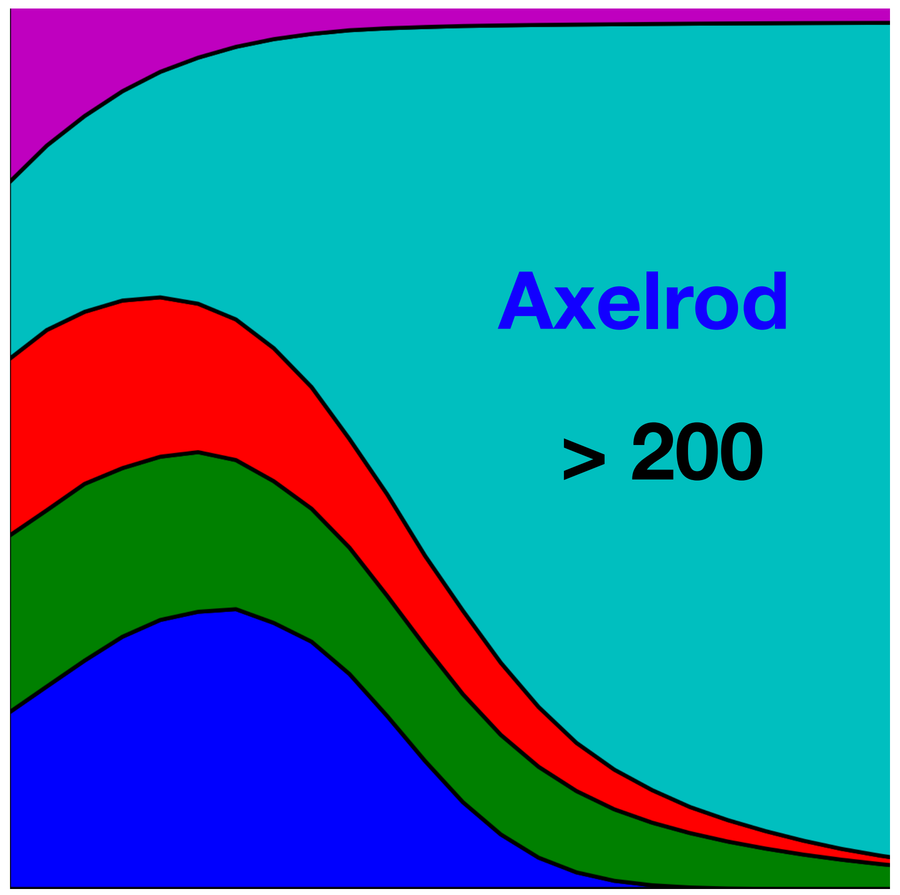

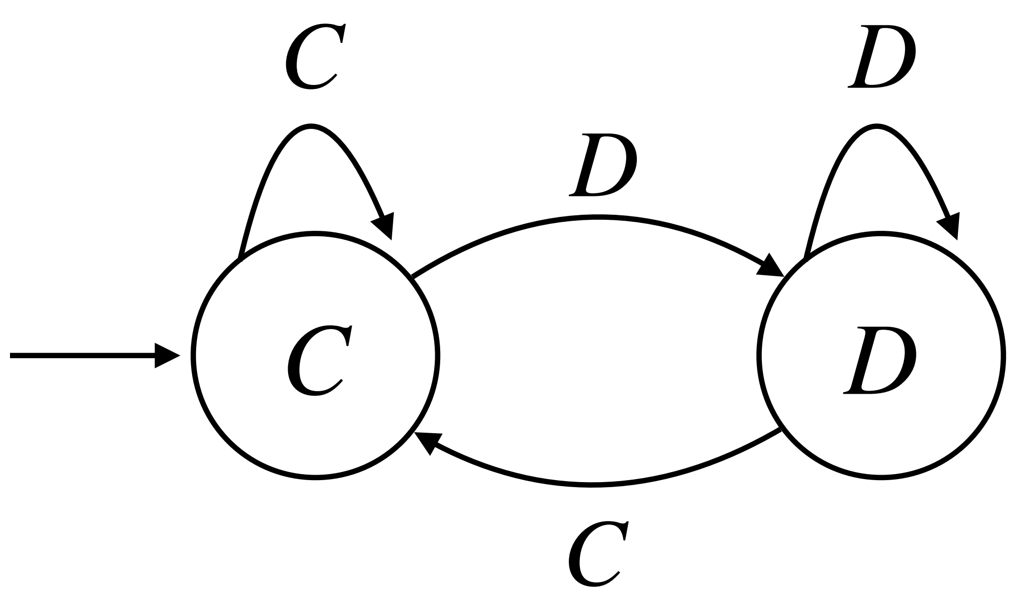

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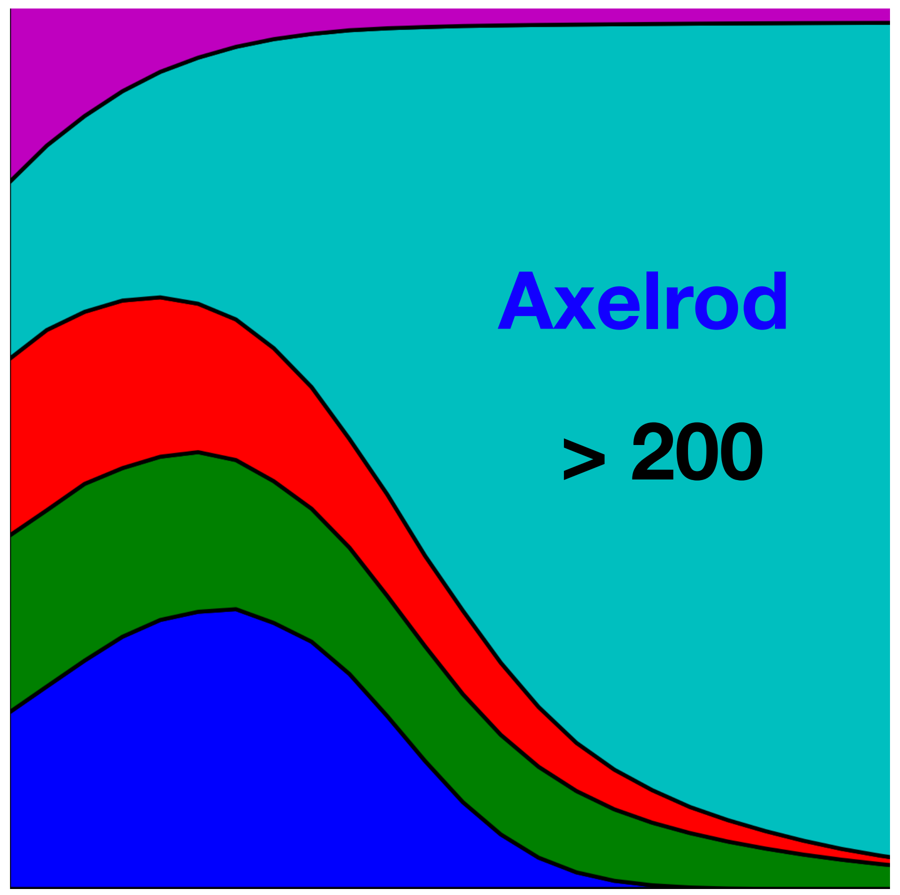

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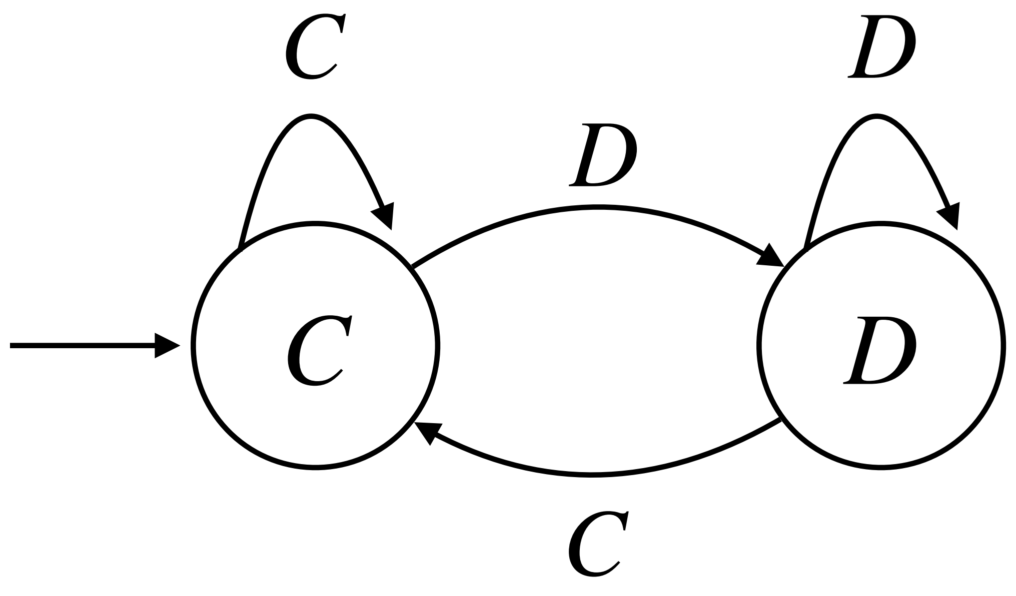

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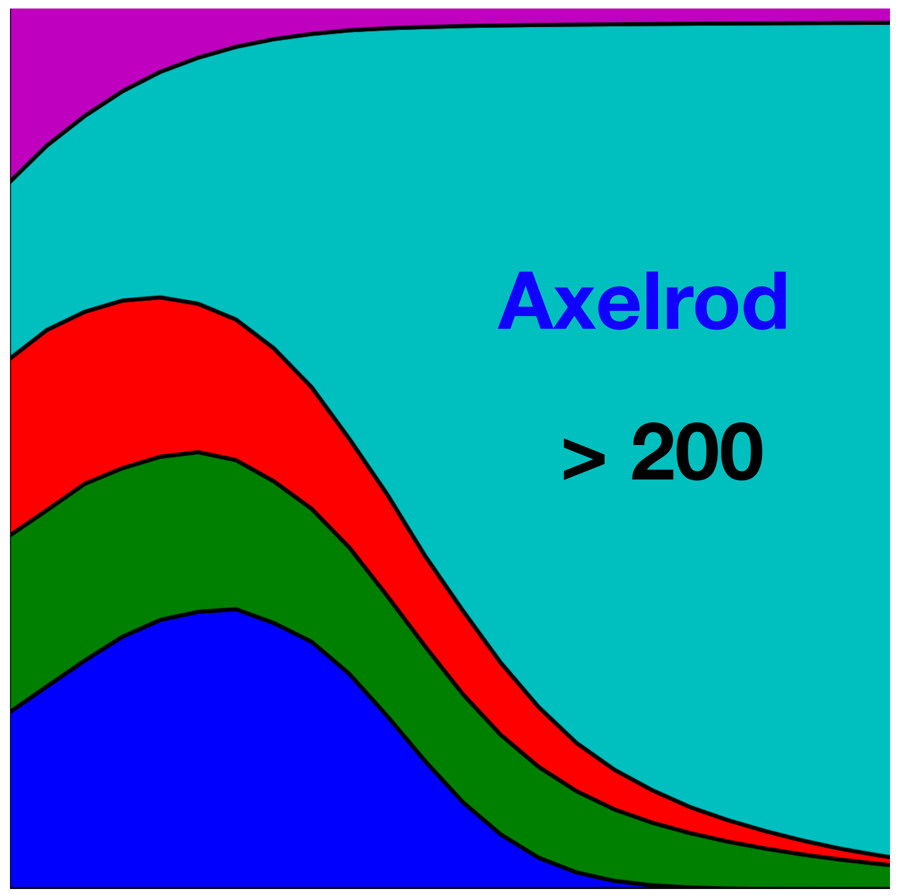

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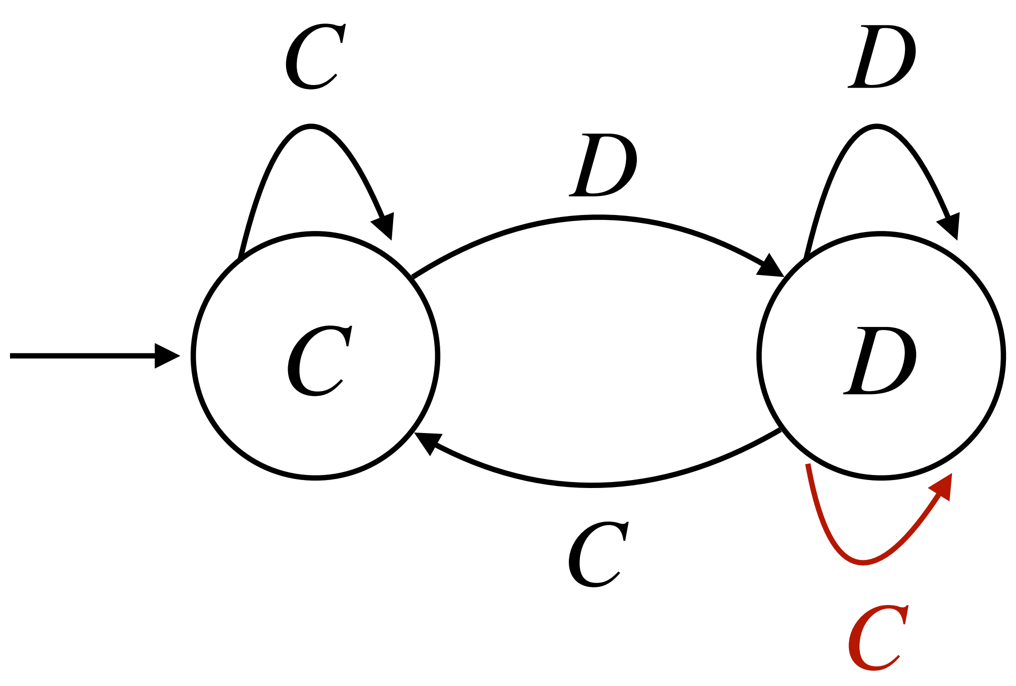

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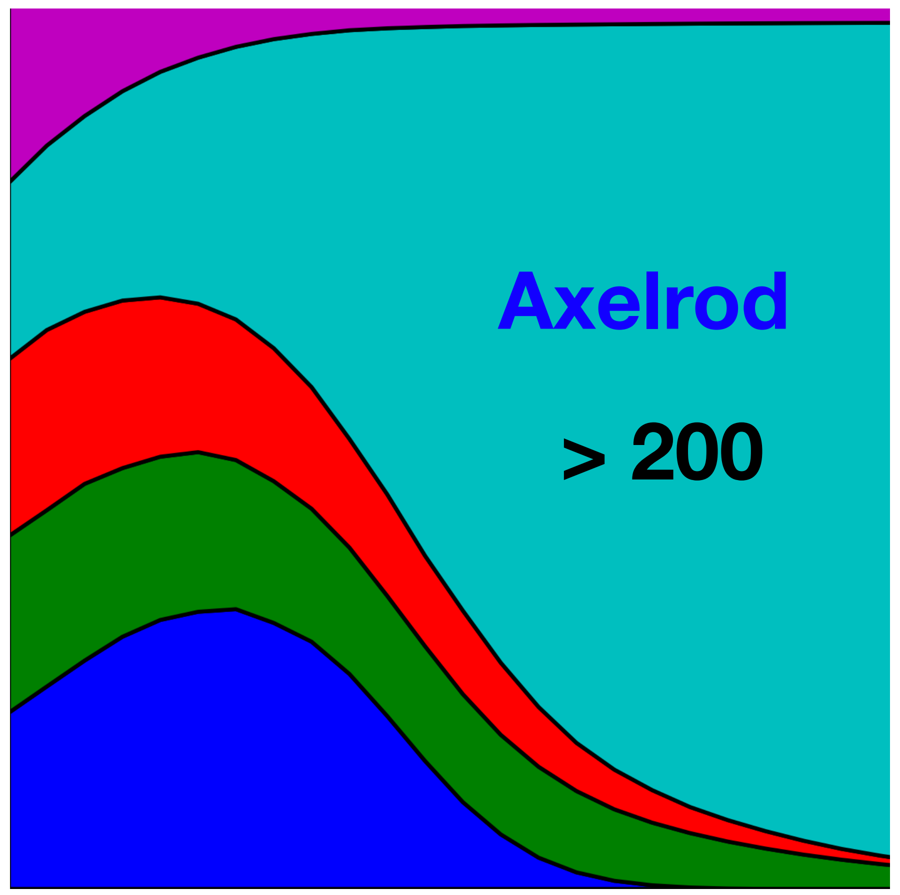

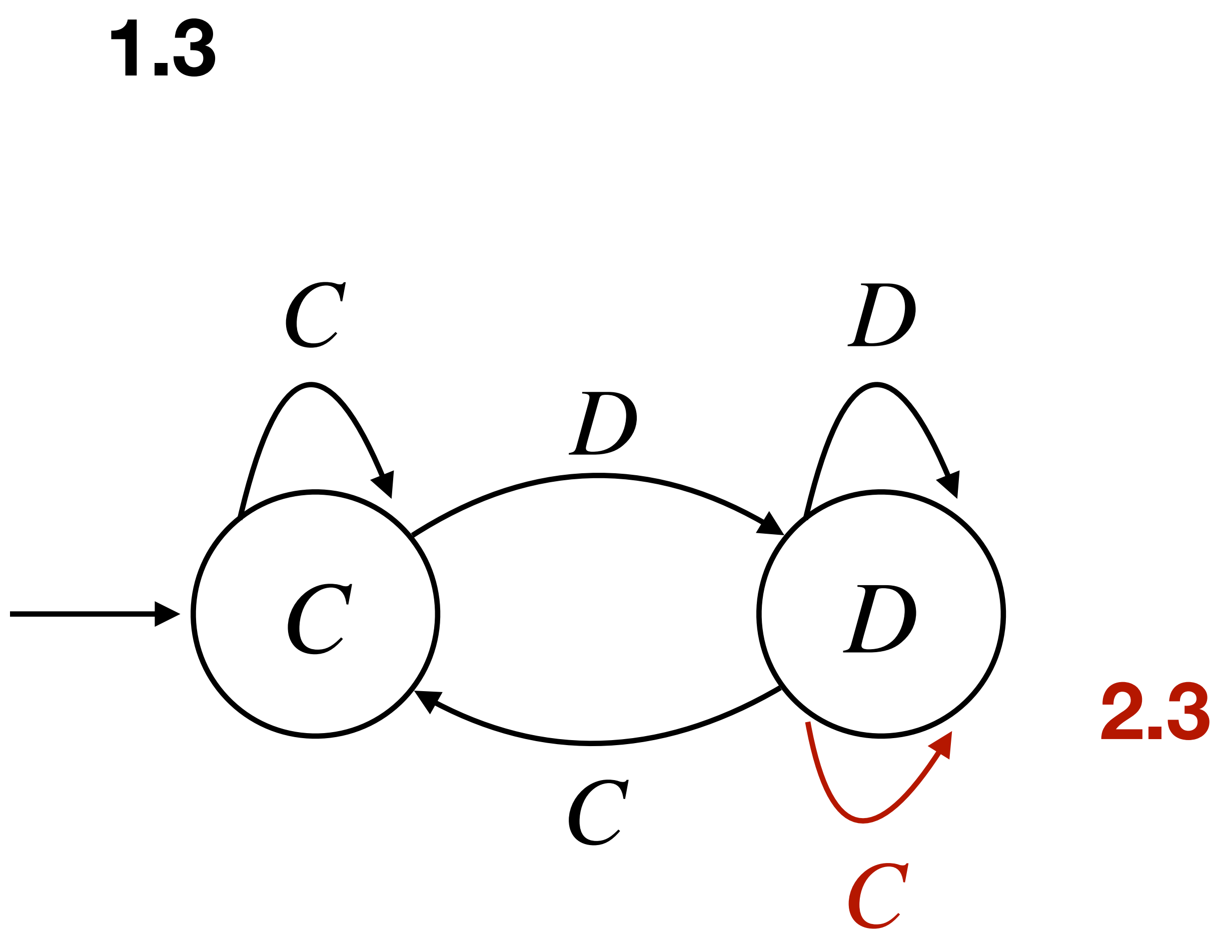

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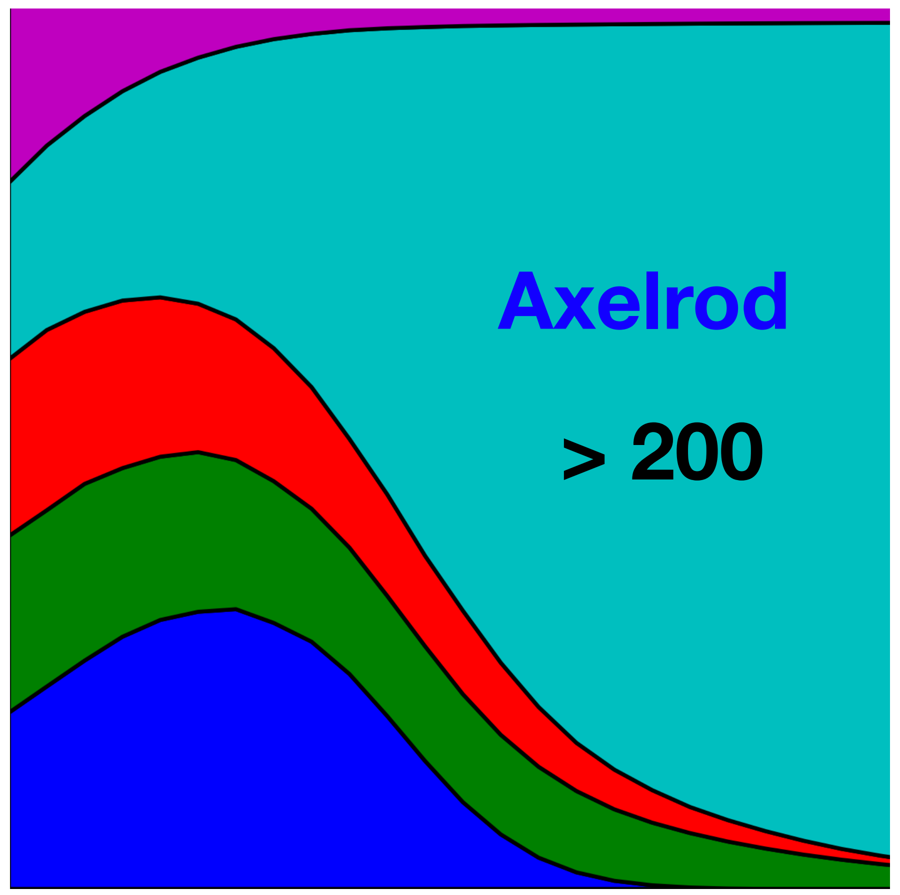

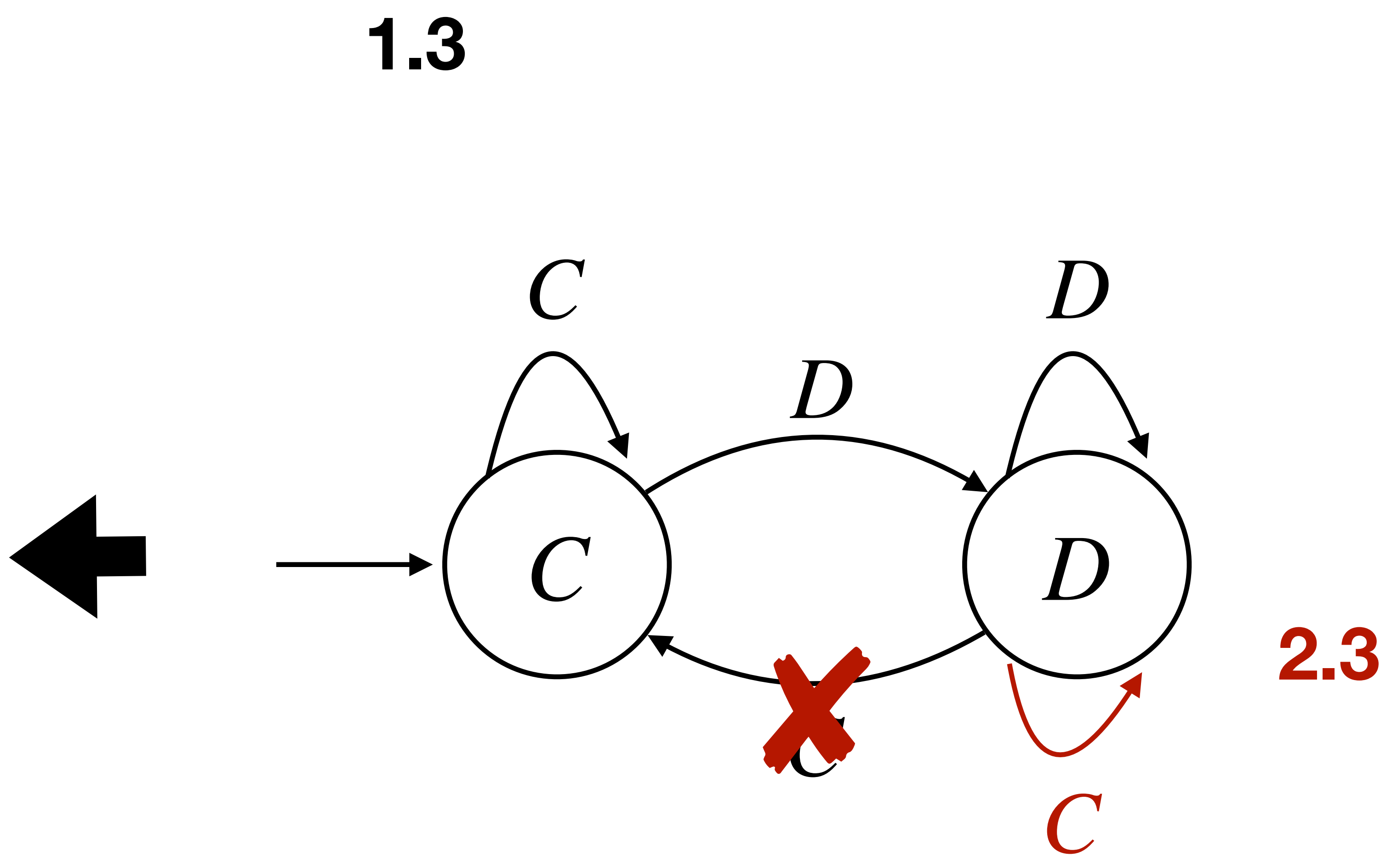

STRATEGIES IN COMPUTER TOURNAMENTS

- From the training emerged strategies that were cooperative but also took advantage of simple strategies

- Strategies trained in environments with errors were more adaptable

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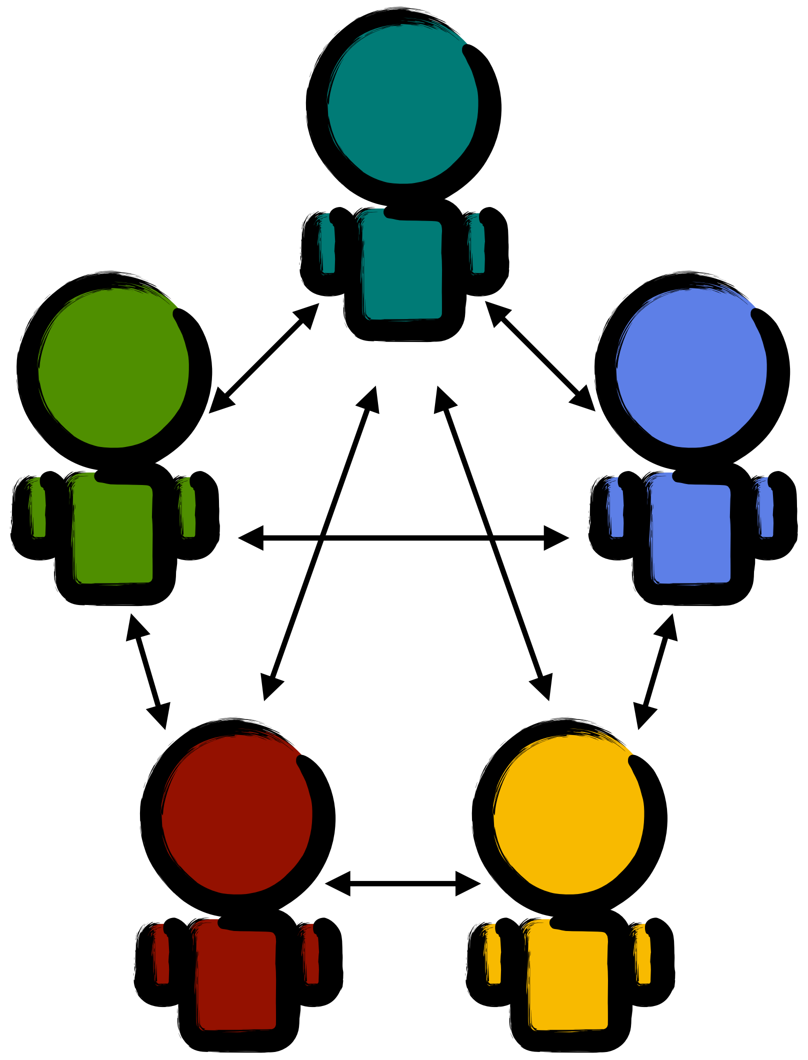
[1] Reinforcement learning produces dominant strategies for the iterated prisoner’s dilemma.
https://doi.org/10.1371/journal.pone.0188046

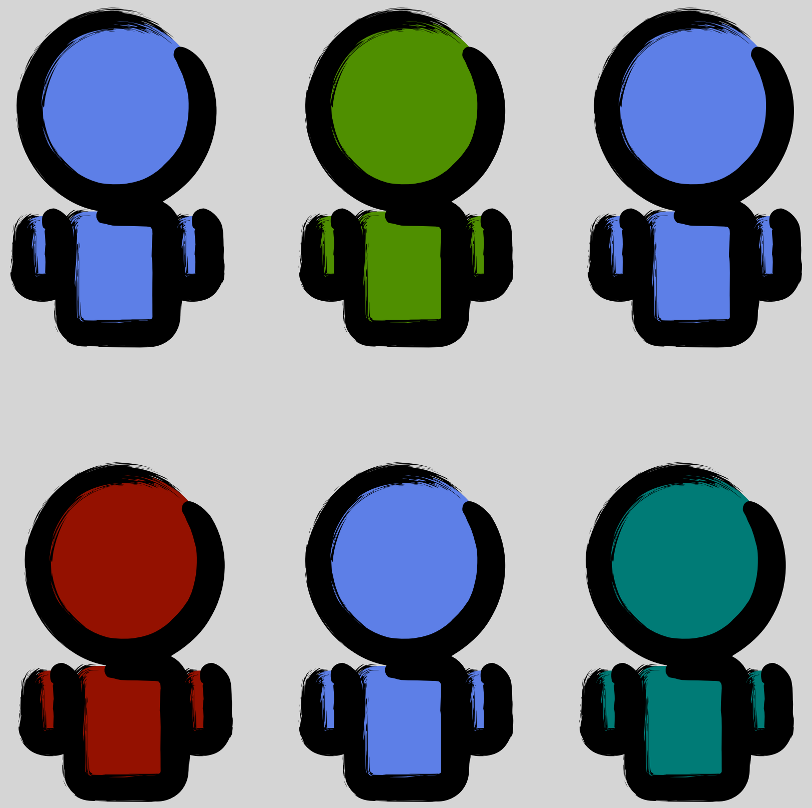
[2] Evolution reinforces cooperation with the emergence of self-recognition mechanisms.
https://doi.org/10.1371/journal.pone.0204981

[3] Properties of Winning Iterated Prisoner's Dilemma Strategies.
https://arxiv.org/abs/2001.05911

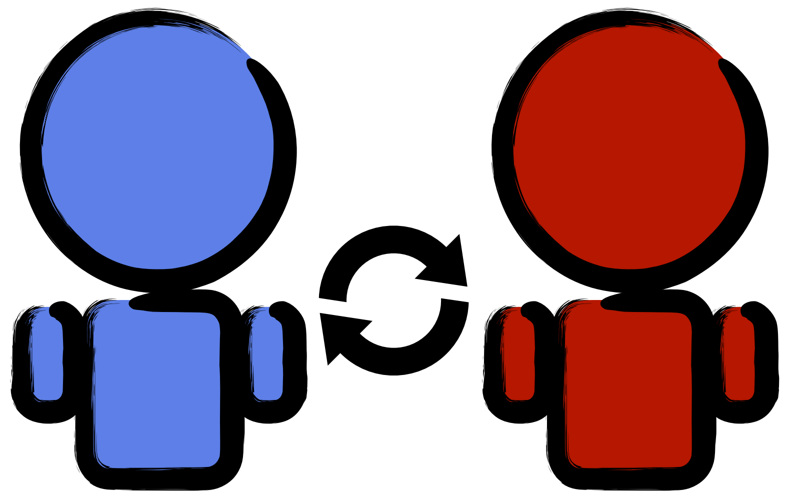
Strategies in computer tournaments



Learning in populations



Strategies in repeated interactions



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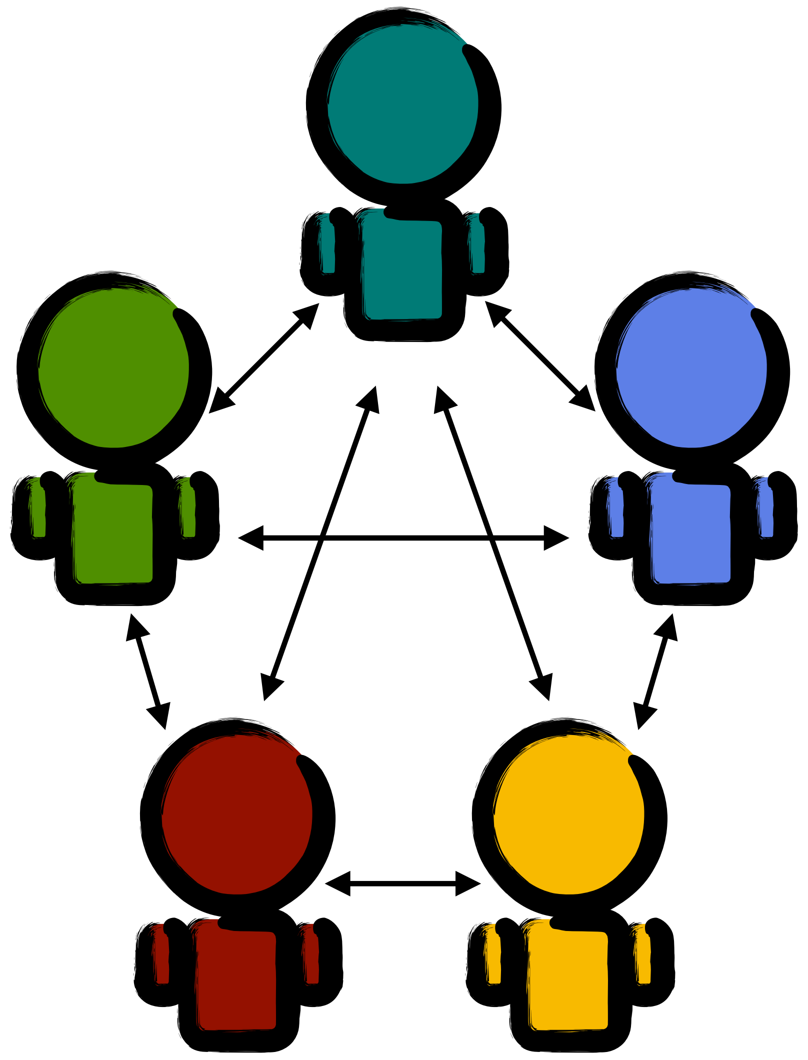

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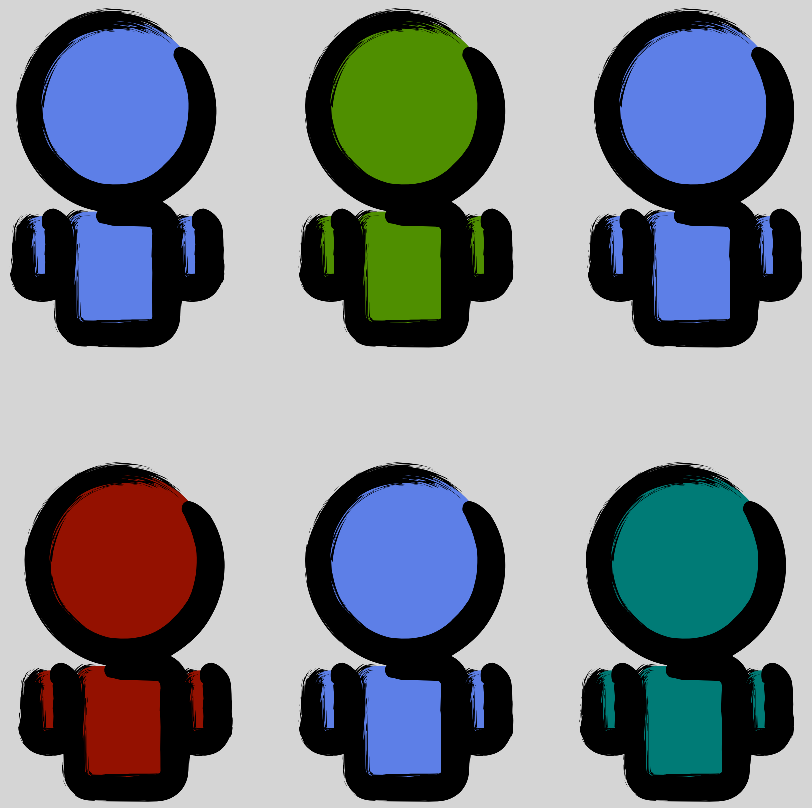

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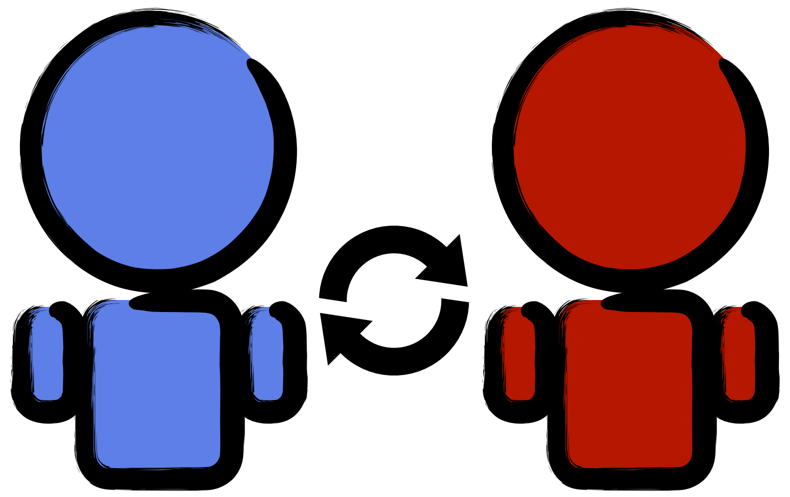
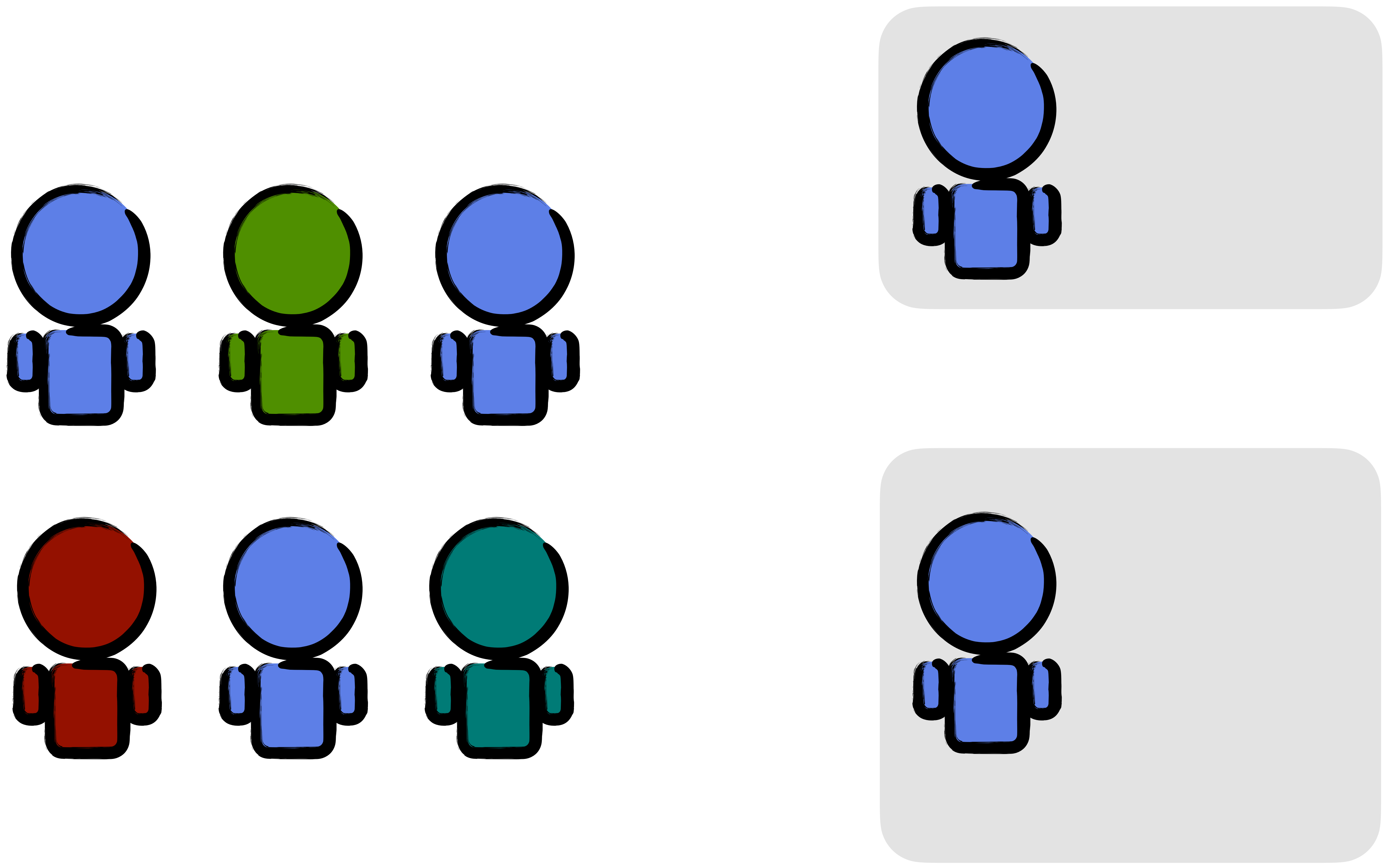
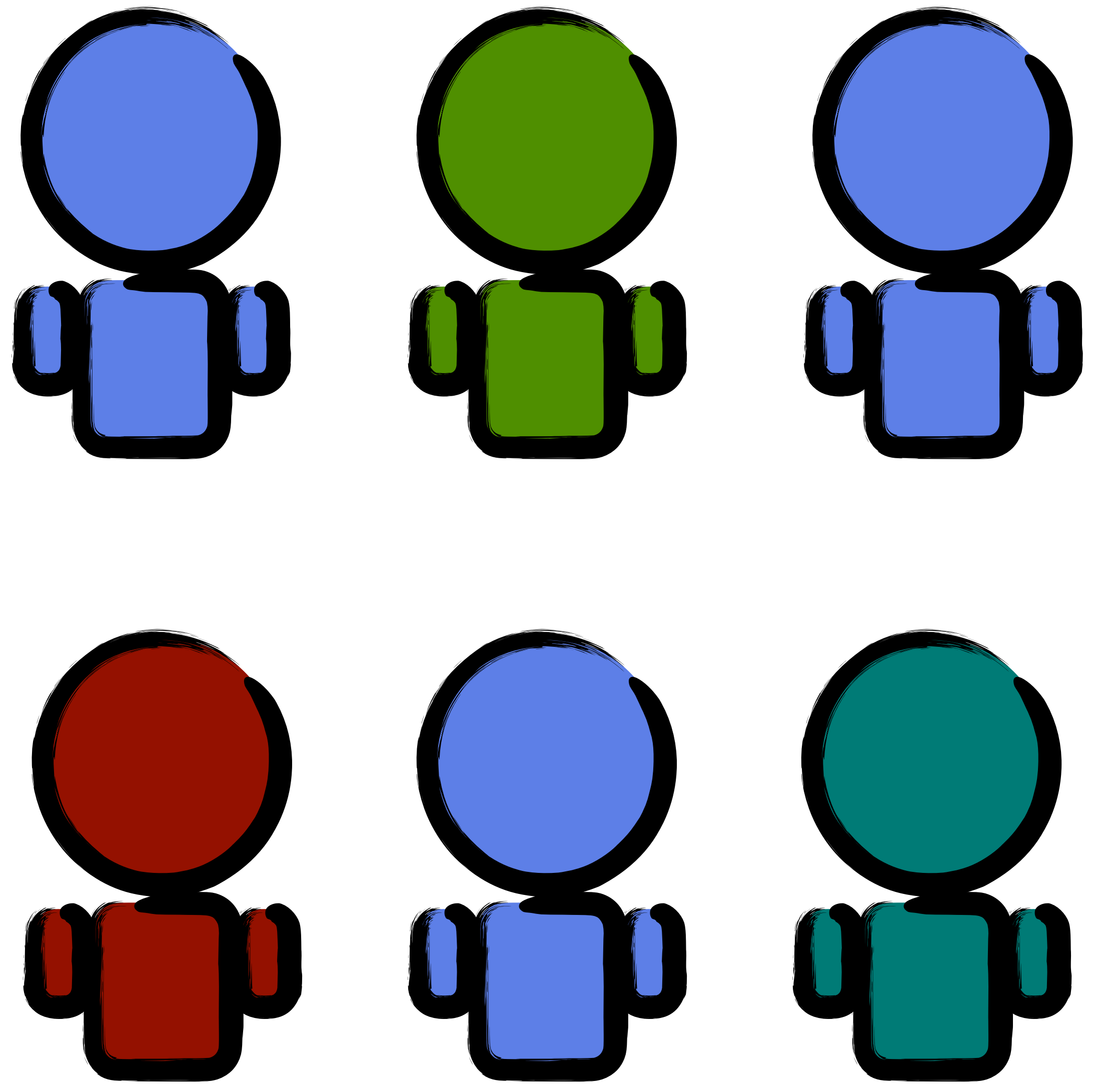
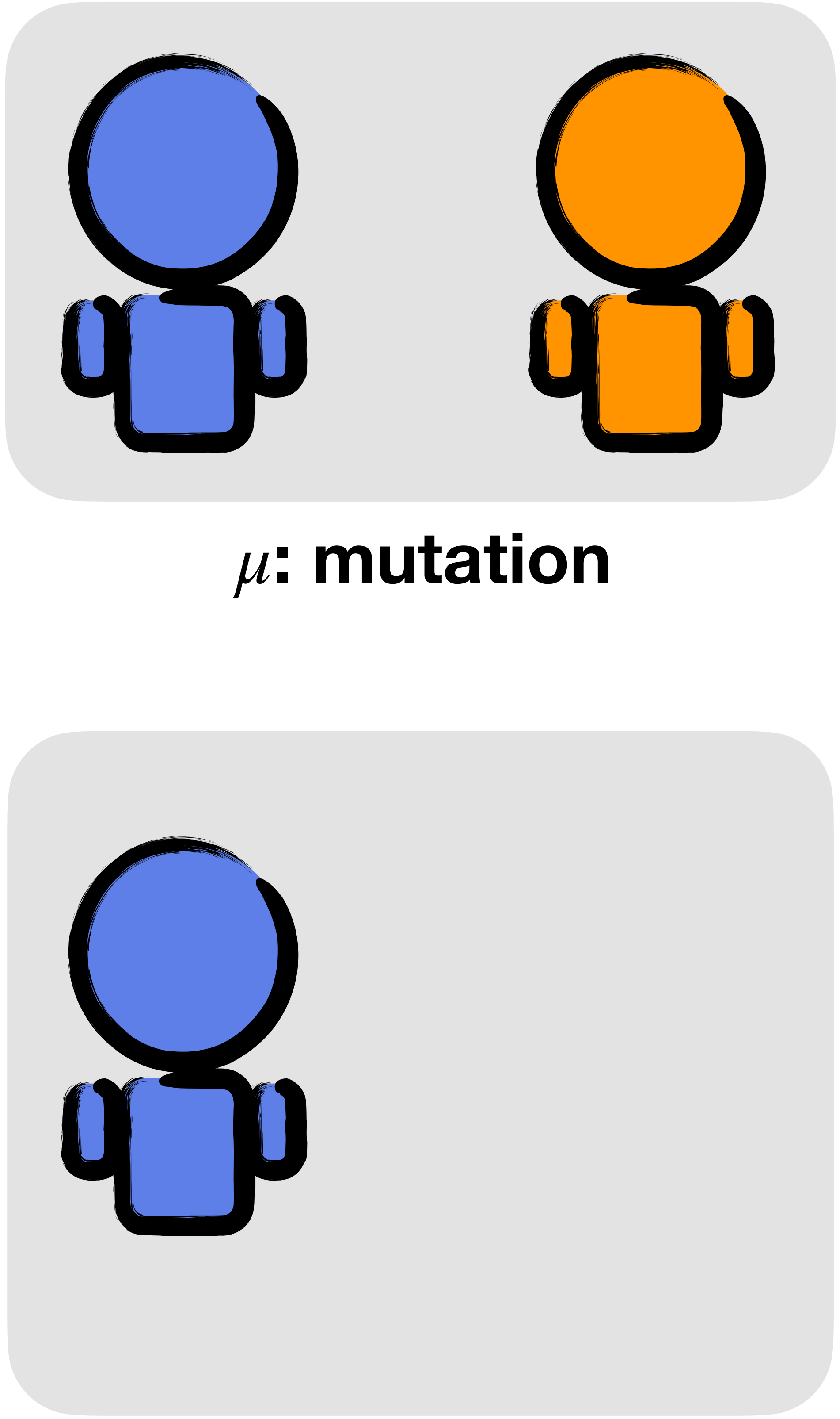


LEARNING IN POPULATIONS



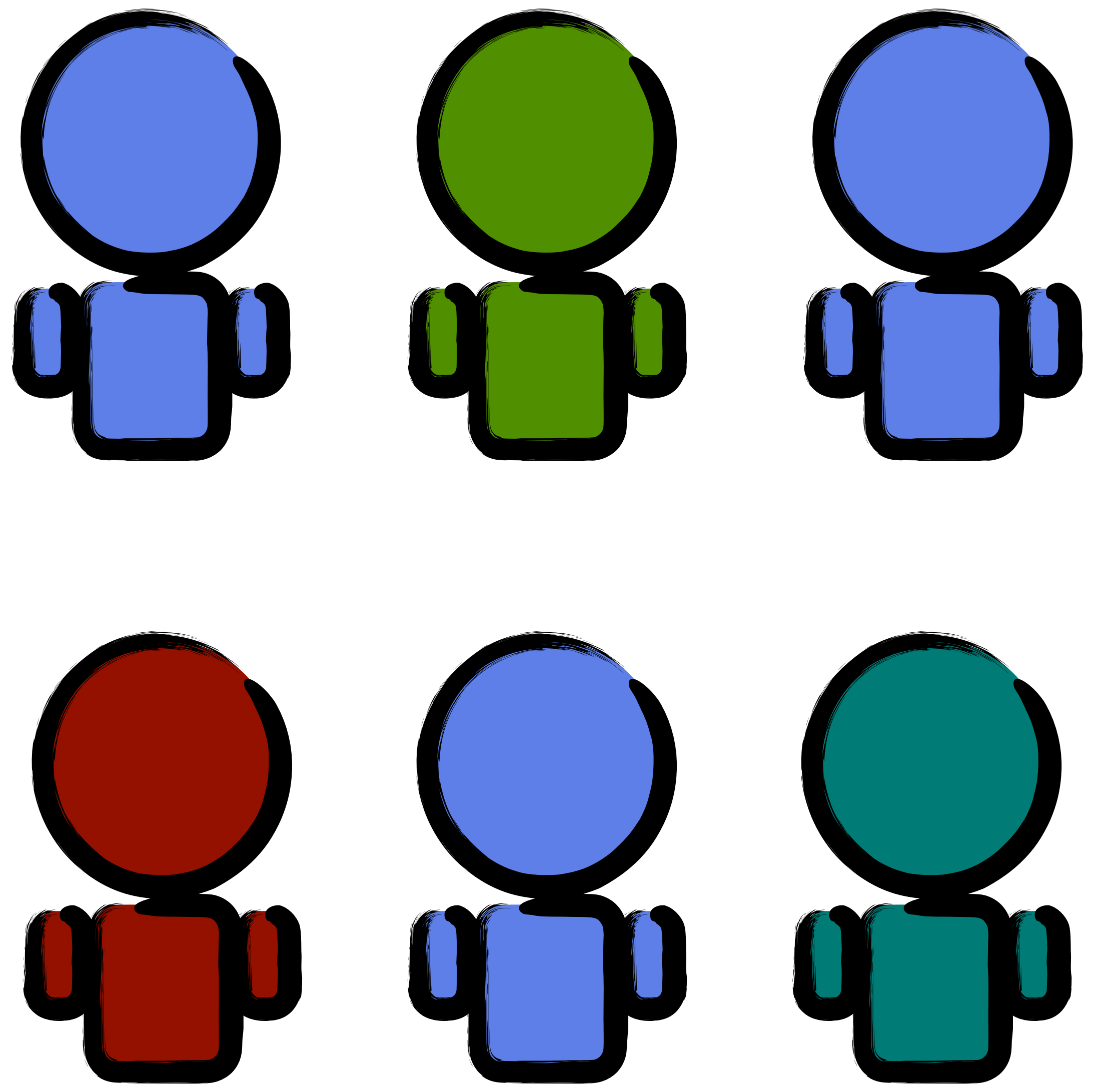
LEARNING IN POPULATIONS

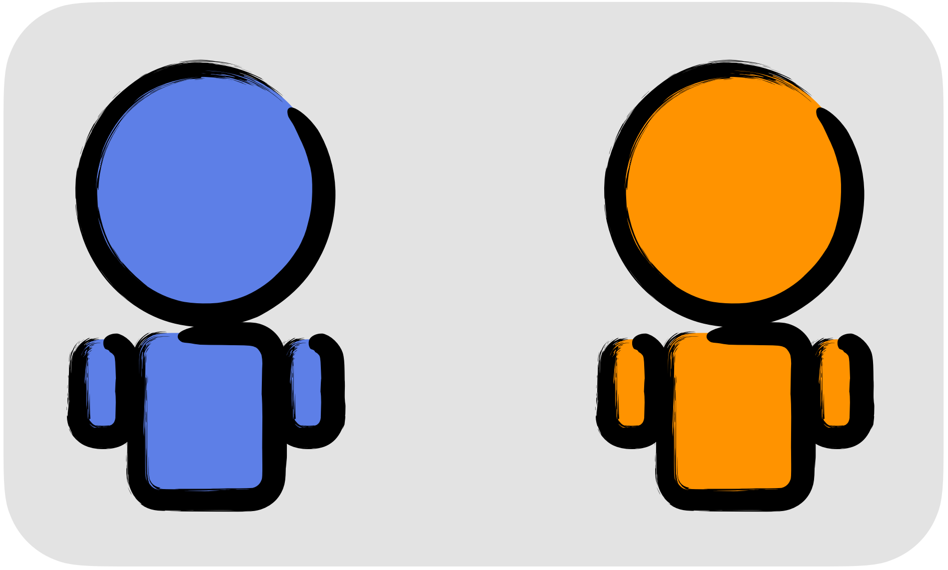




μ: **mutation**

LEARNING IN POPULATIONS





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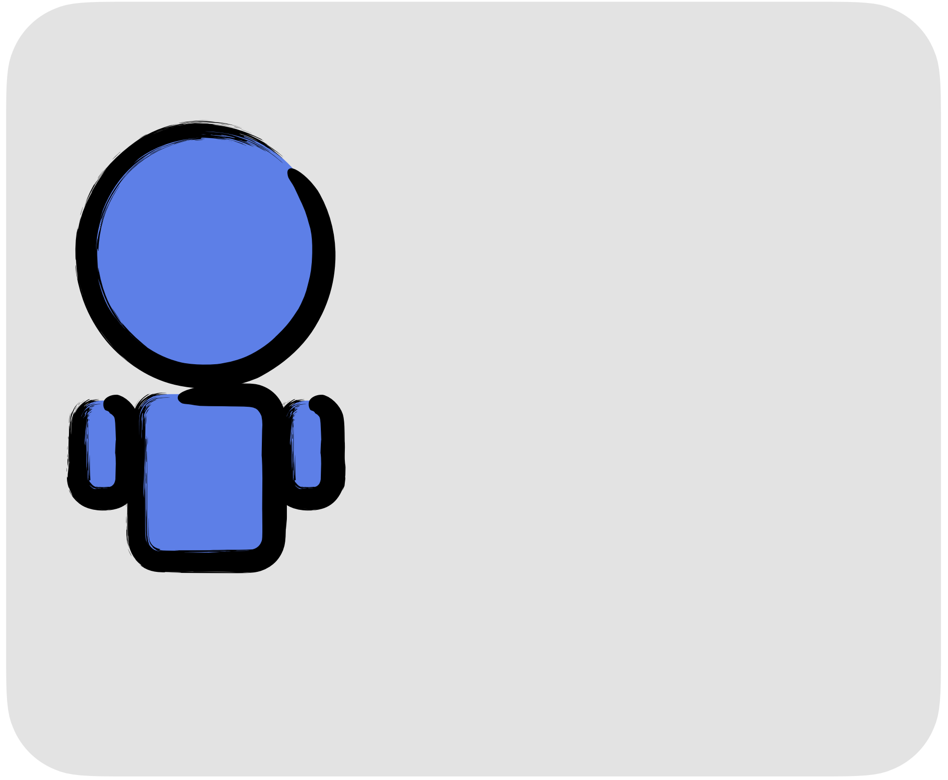
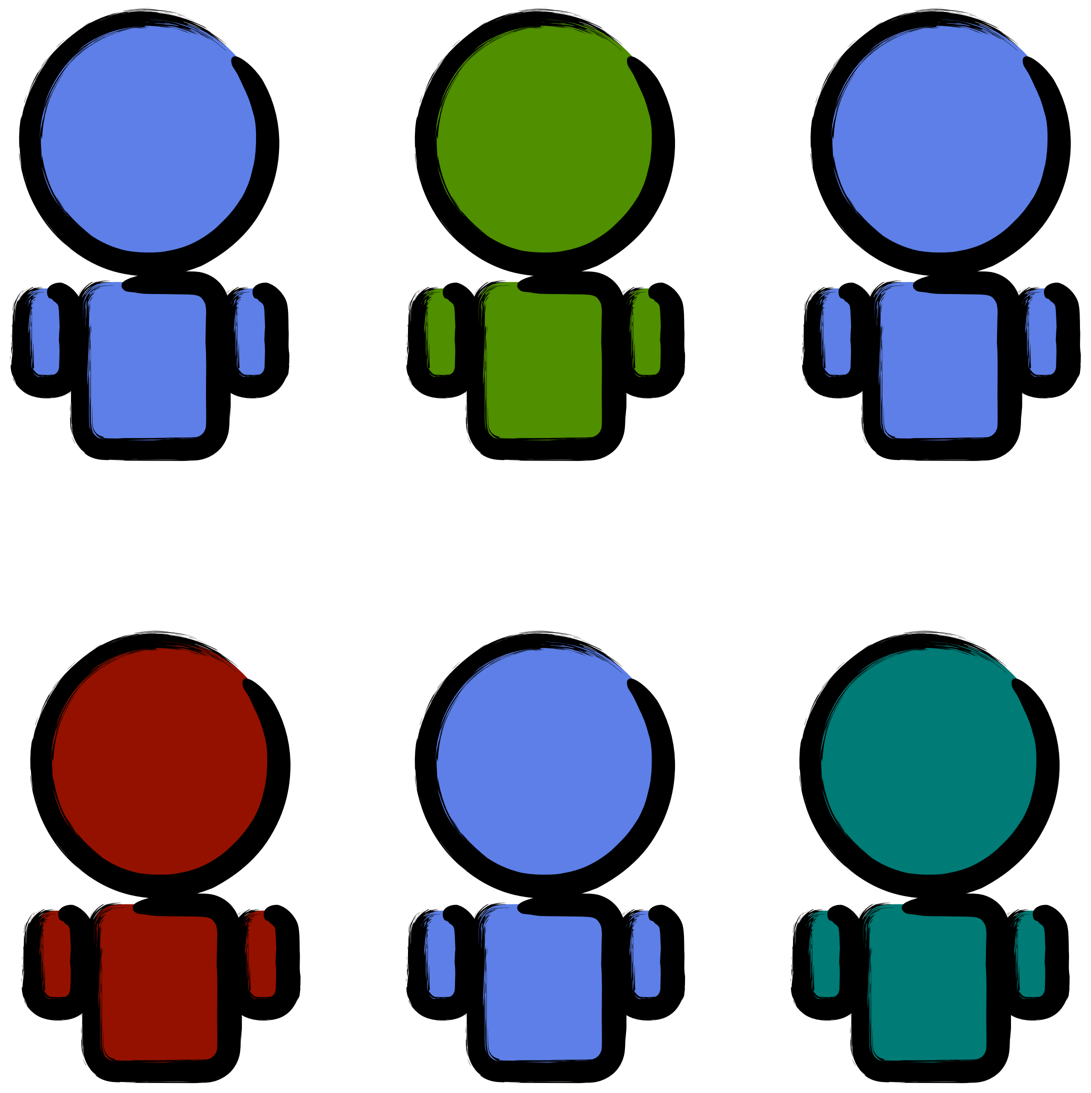
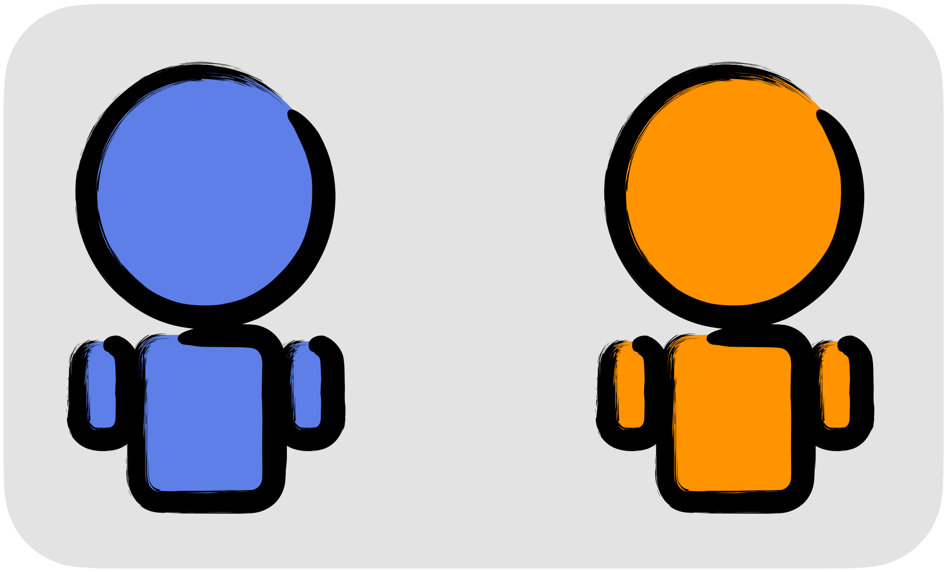


$1 - \mu$: **imitaton**

LEARNING IN POPULATIONS





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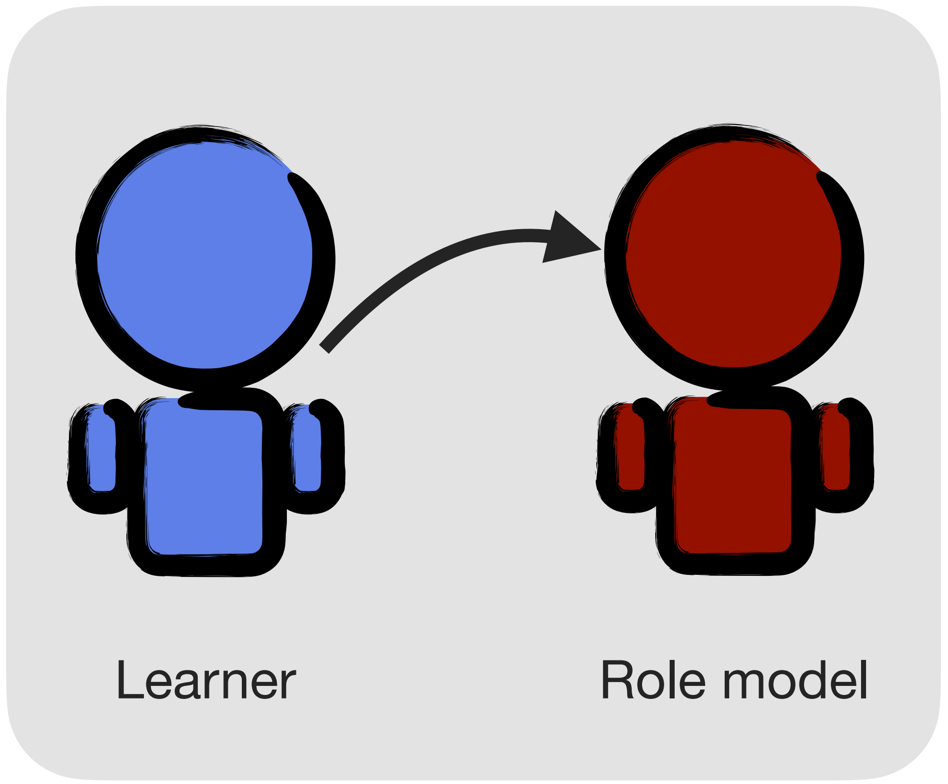
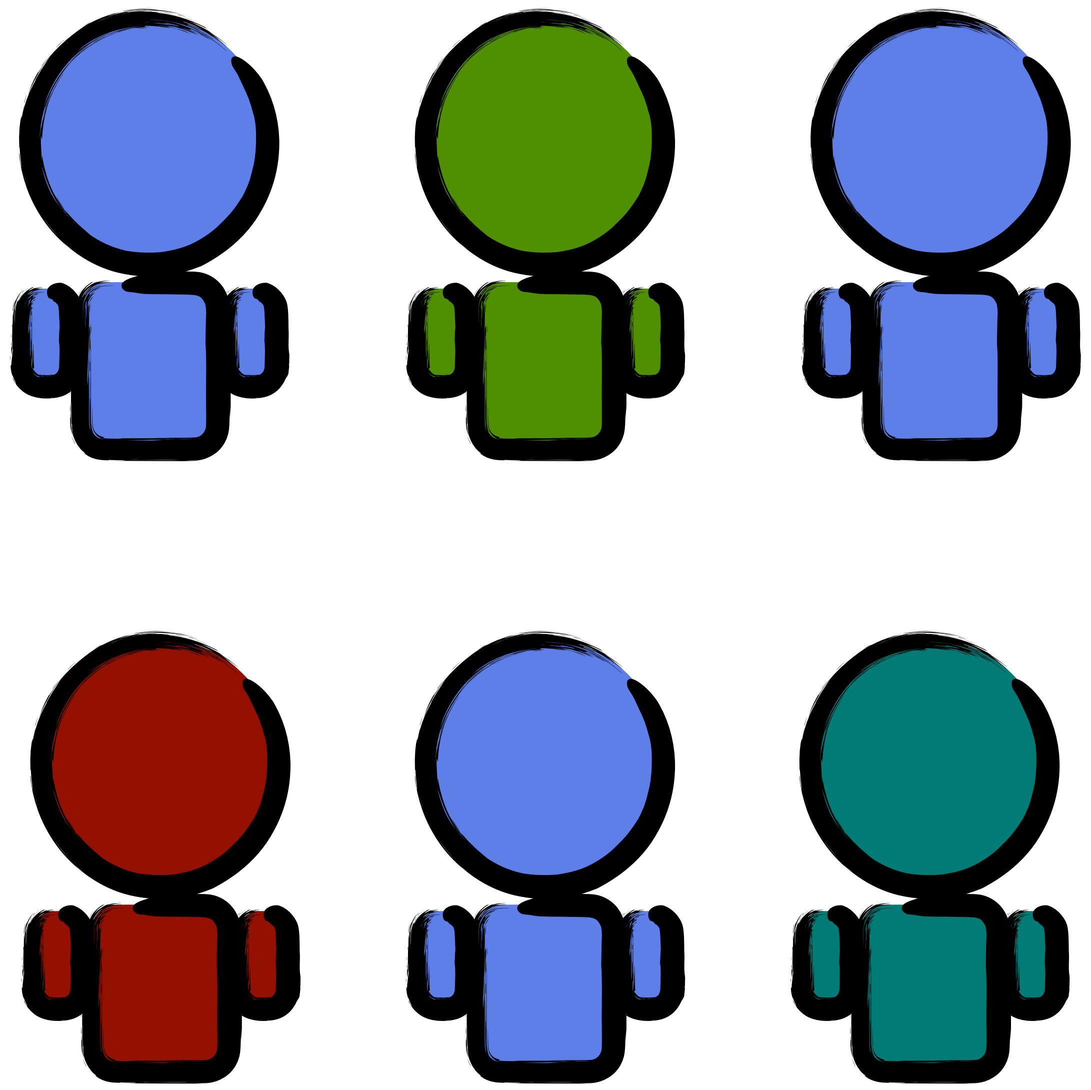
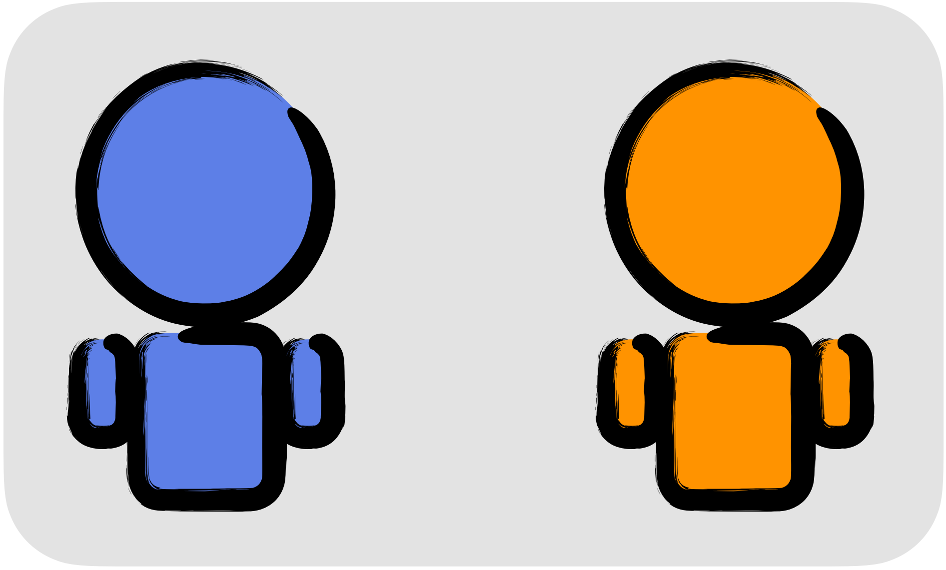


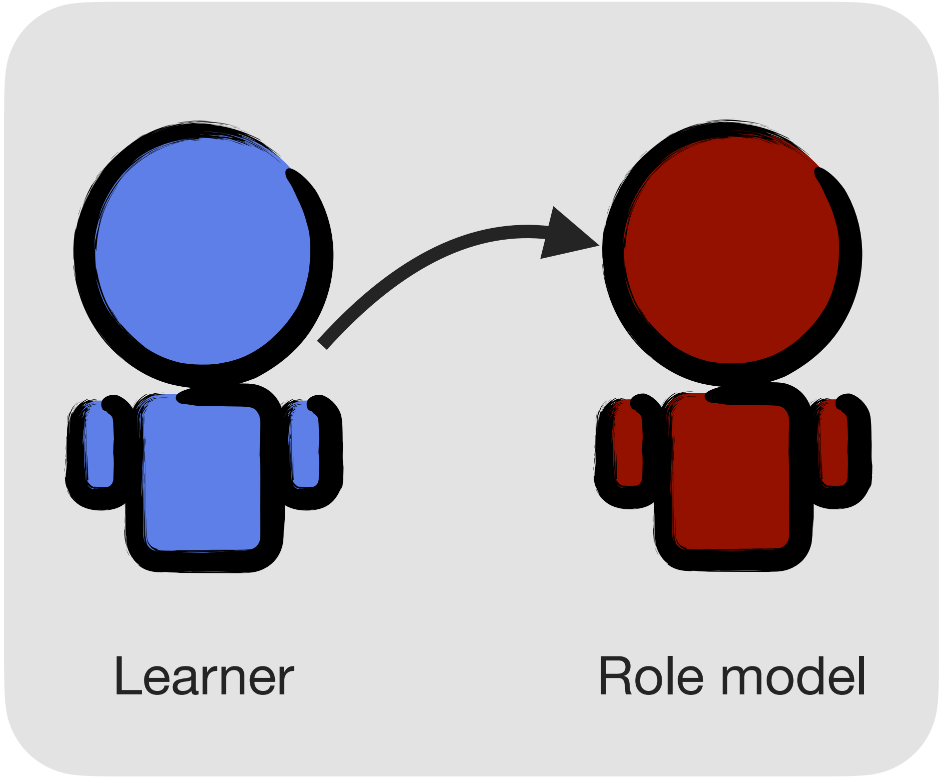
$1 - \mu$: **imitaton**

LEARNING IN POPULATIONS





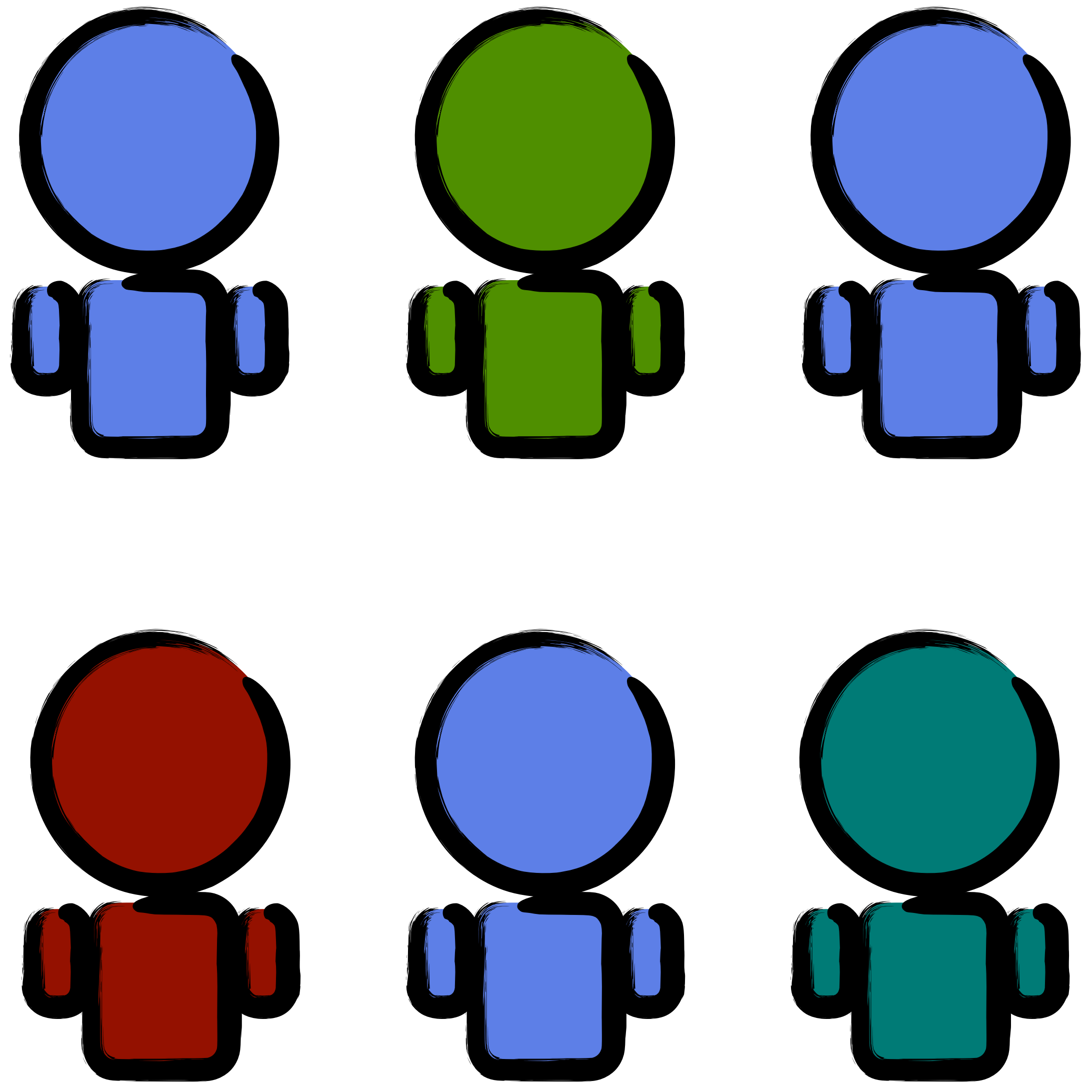
μ: **mutation**

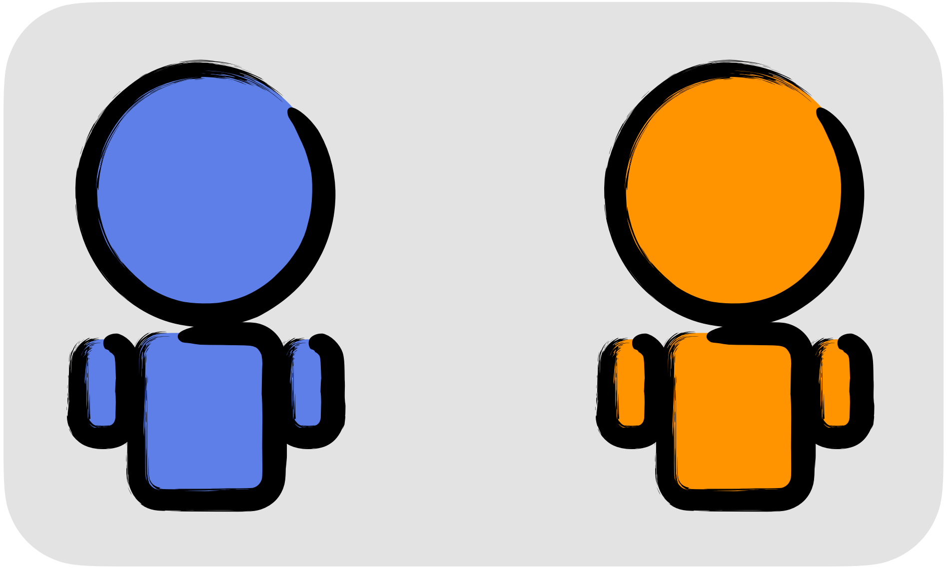


$$\phi(\pi_L, \pi_{RM}) = \frac{1}{1+e^{-\beta(\pi_{blue}-\pi_{red})}}$$

$1-\mu$: **imitaton**

LEARNING IN POPULATIONS





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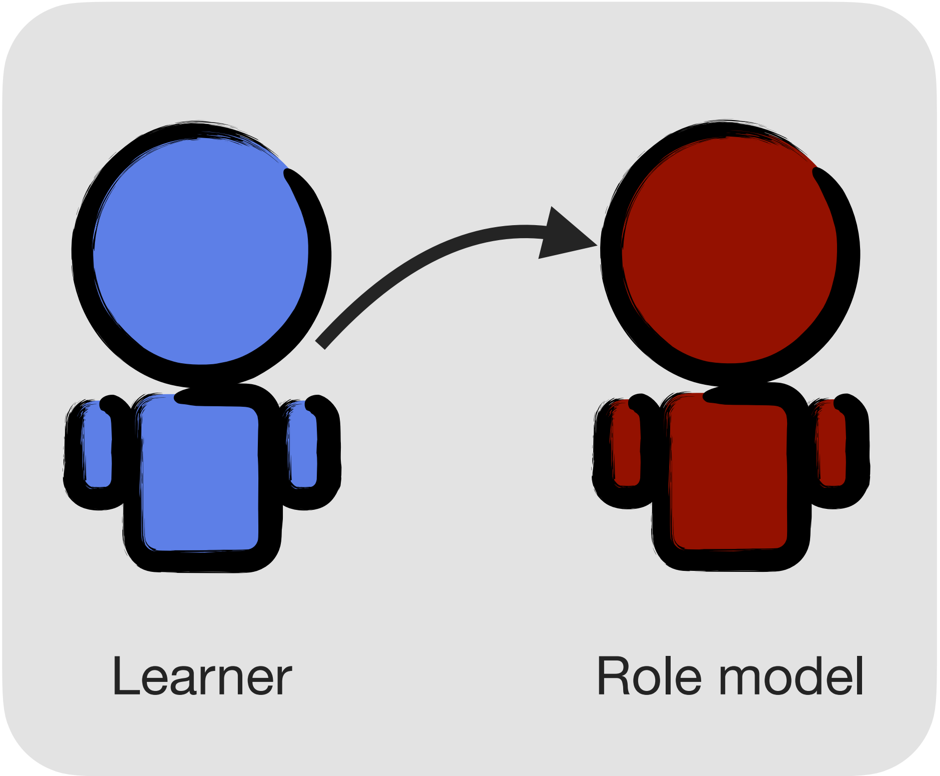
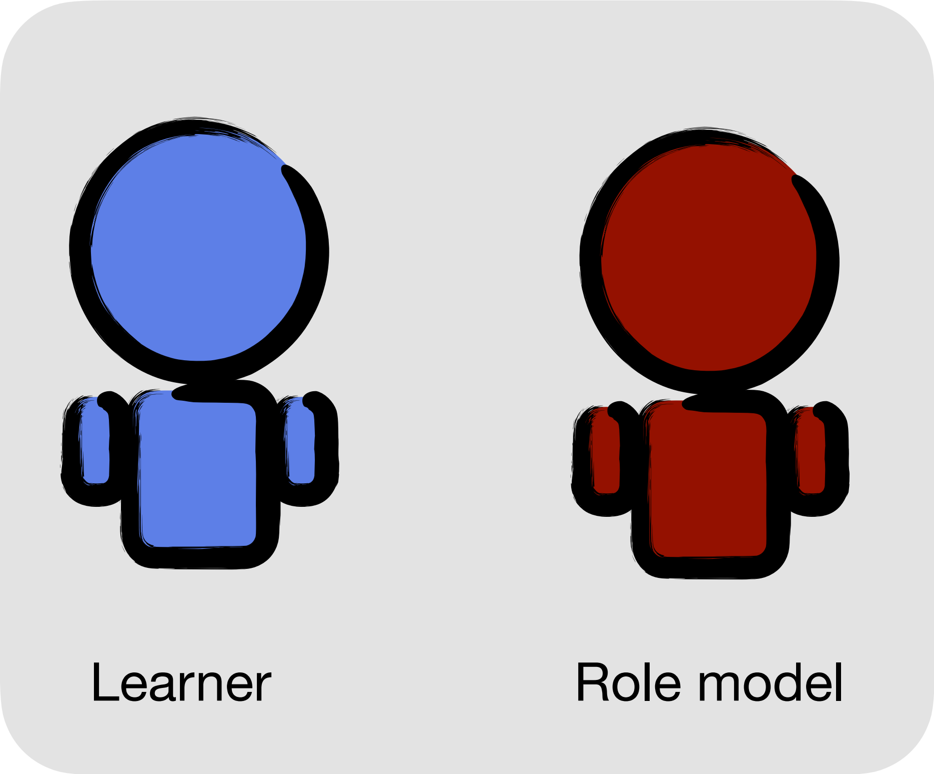


$1-\mu$: **imitaton**

$$\phi(\pi_L, \pi_{RM}) = \frac{1}{1+e^{-\beta(\pi_{blue}-\pi_{red})}}$$

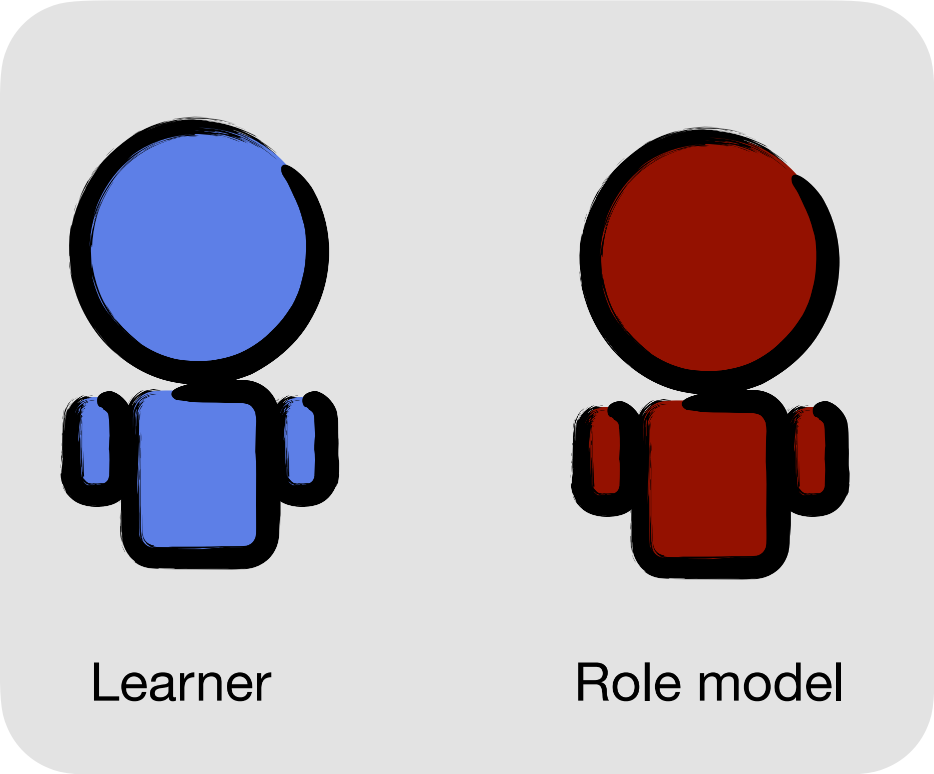
β: **strength of selection**

LEARNING IN POPULATIONS



$1 - \mu$: **imitaton**

LEARNING IN POPULATIONS



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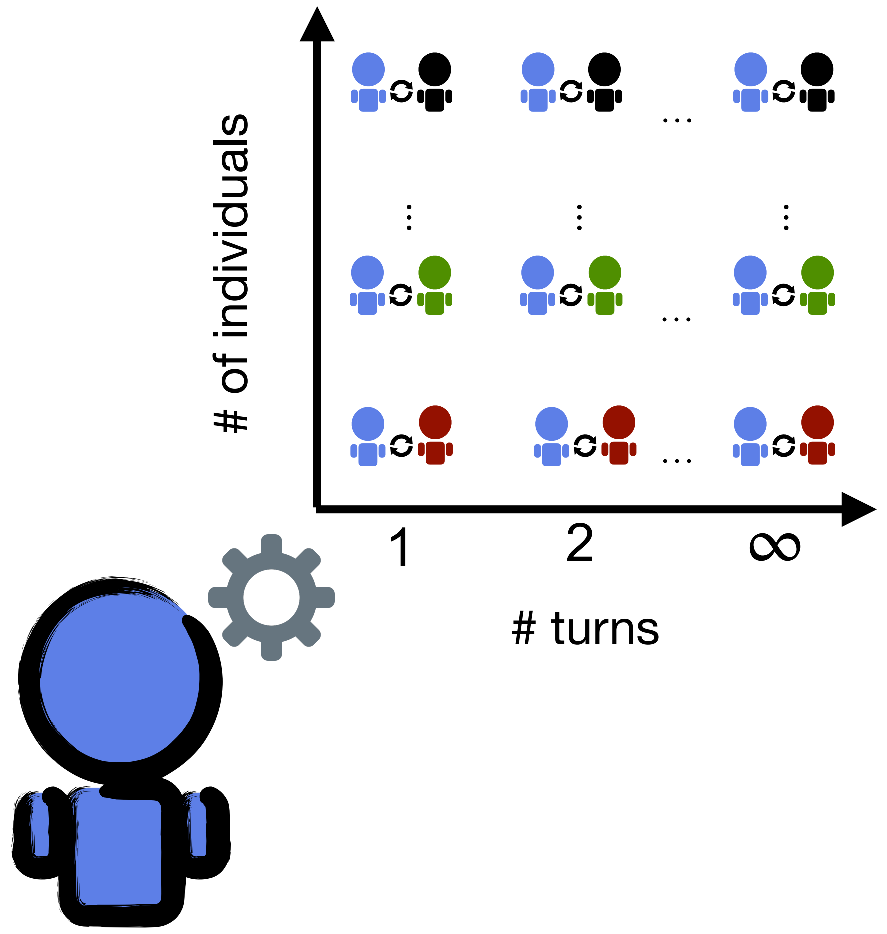

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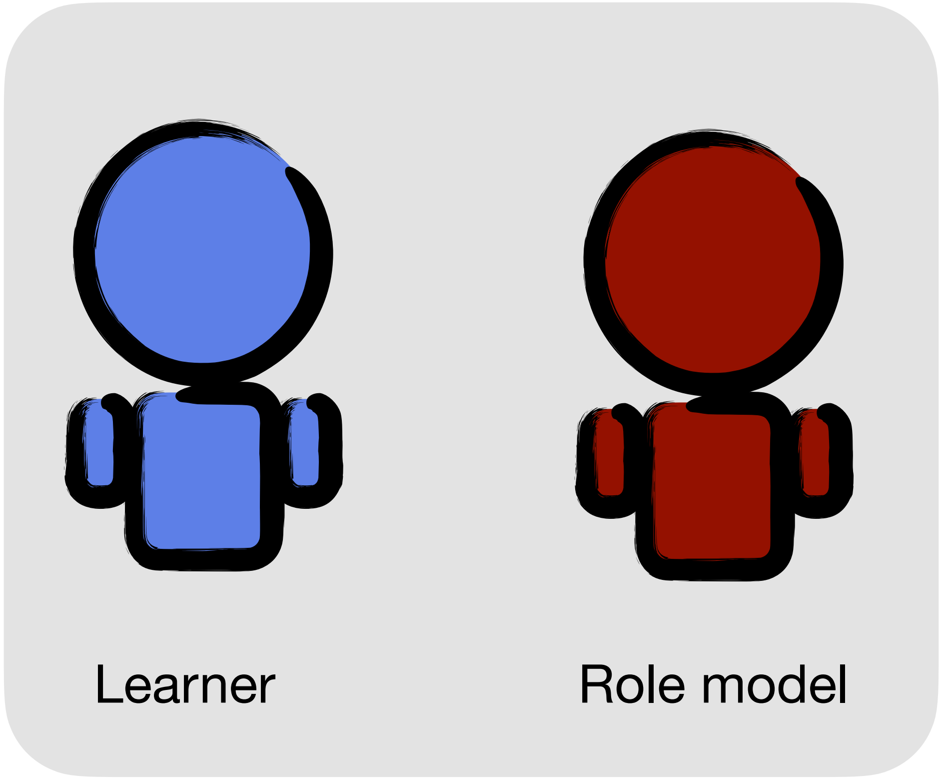

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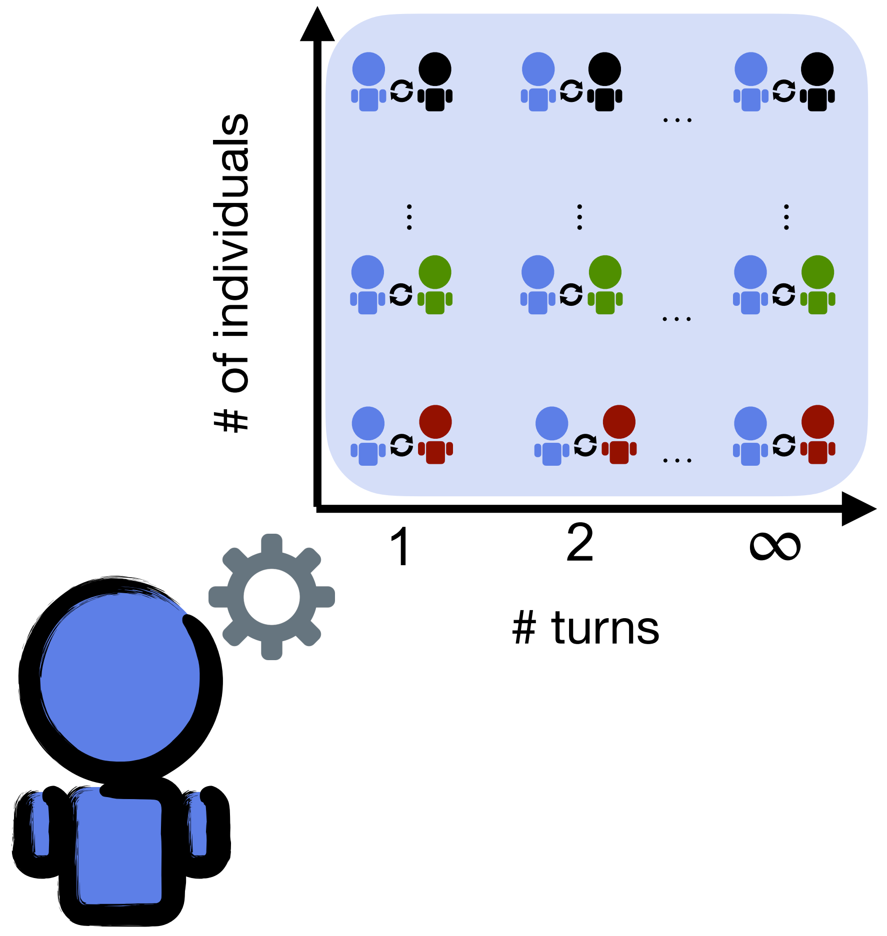

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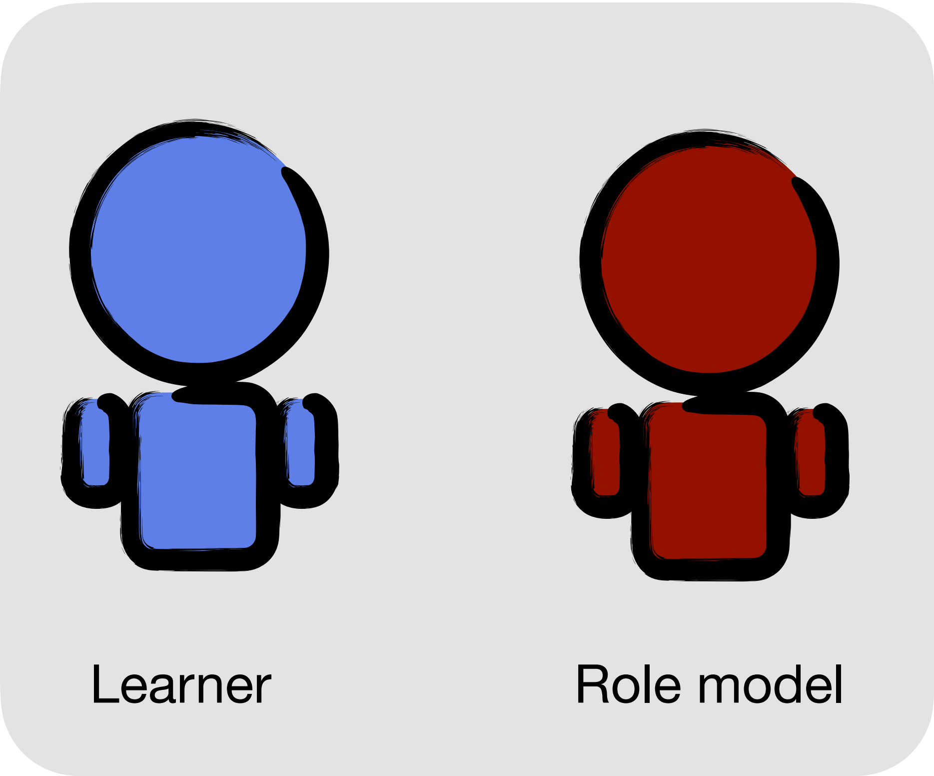

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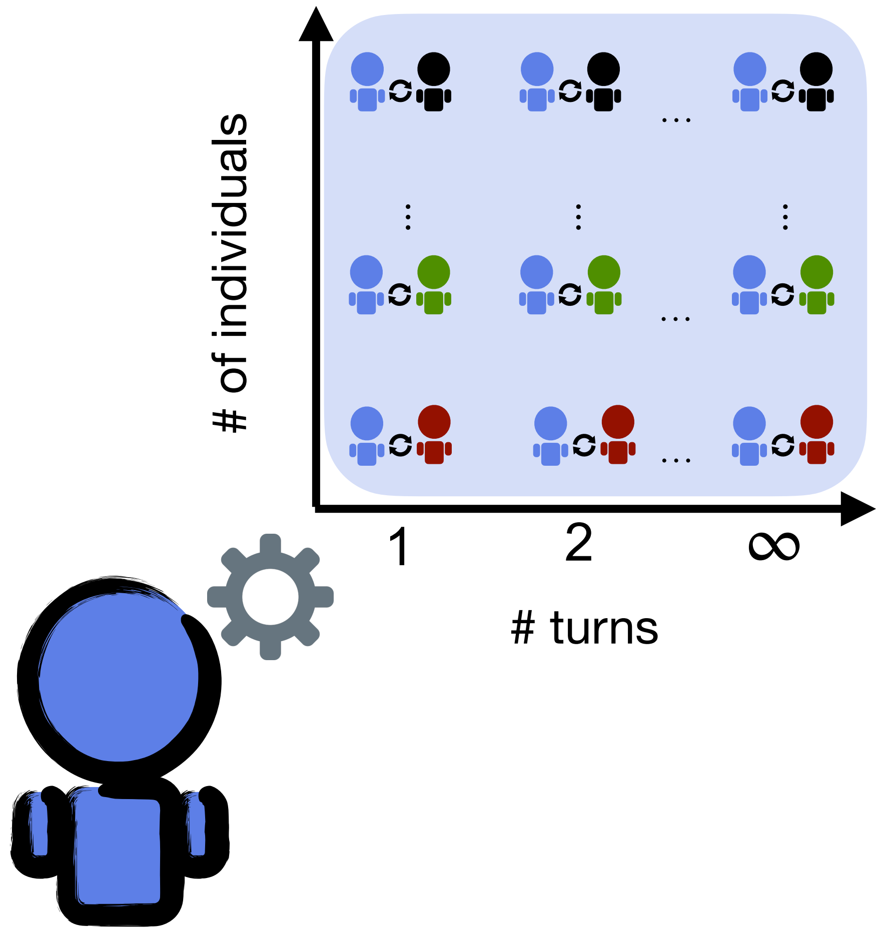

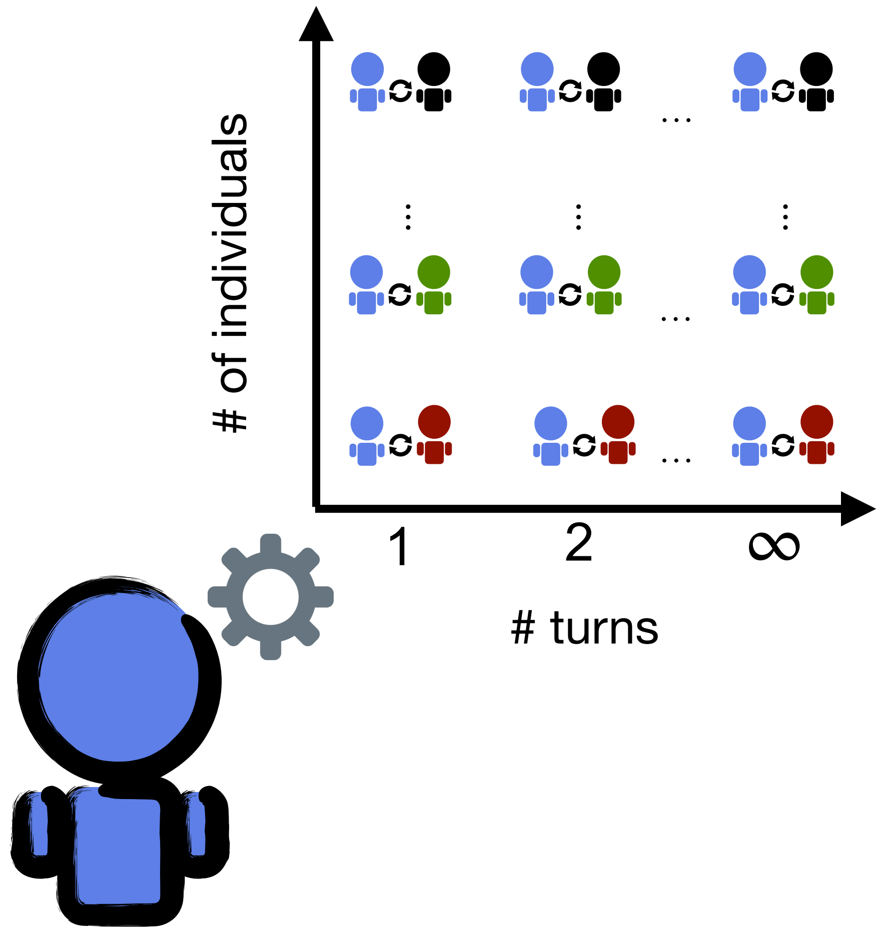

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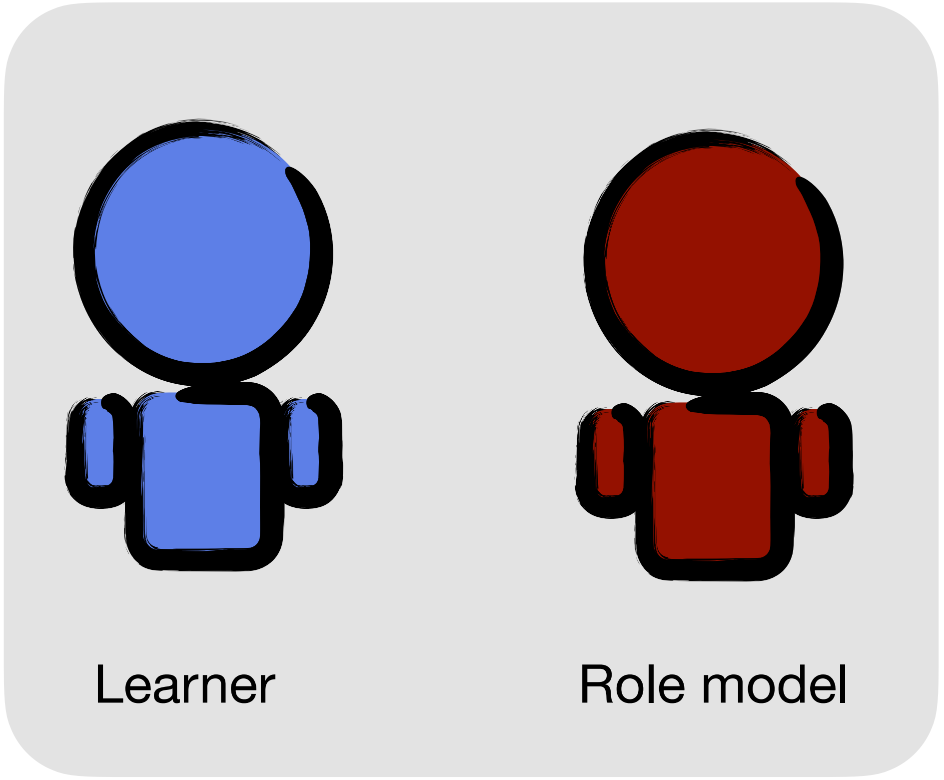

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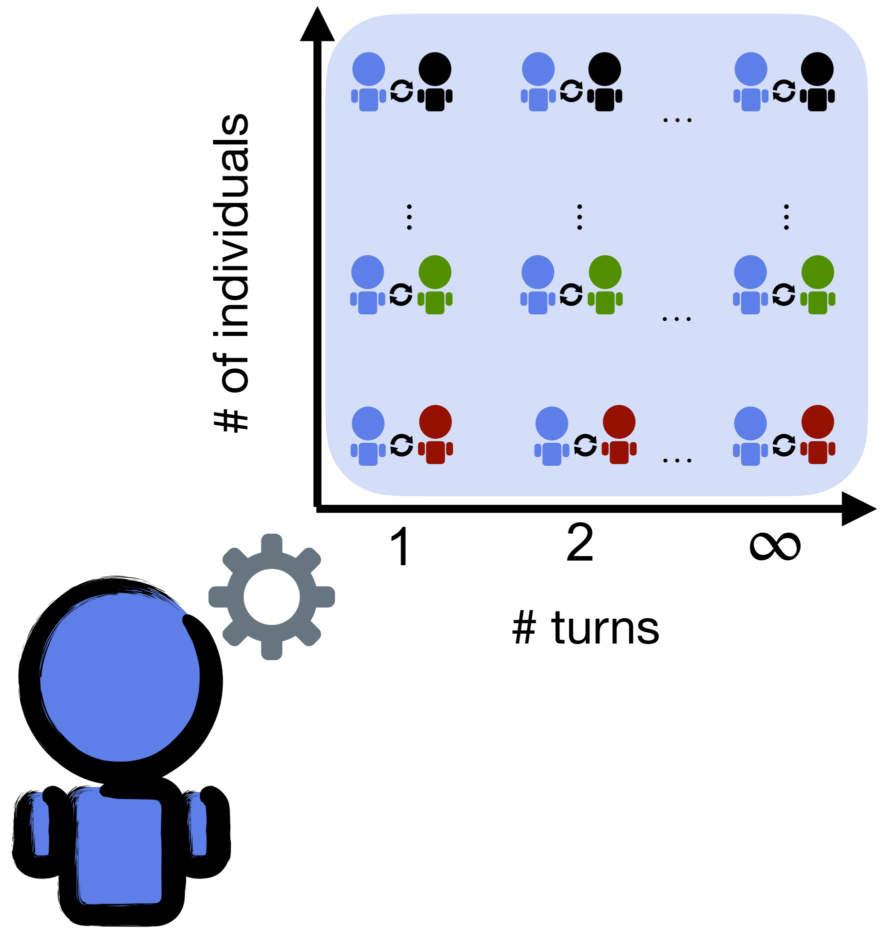

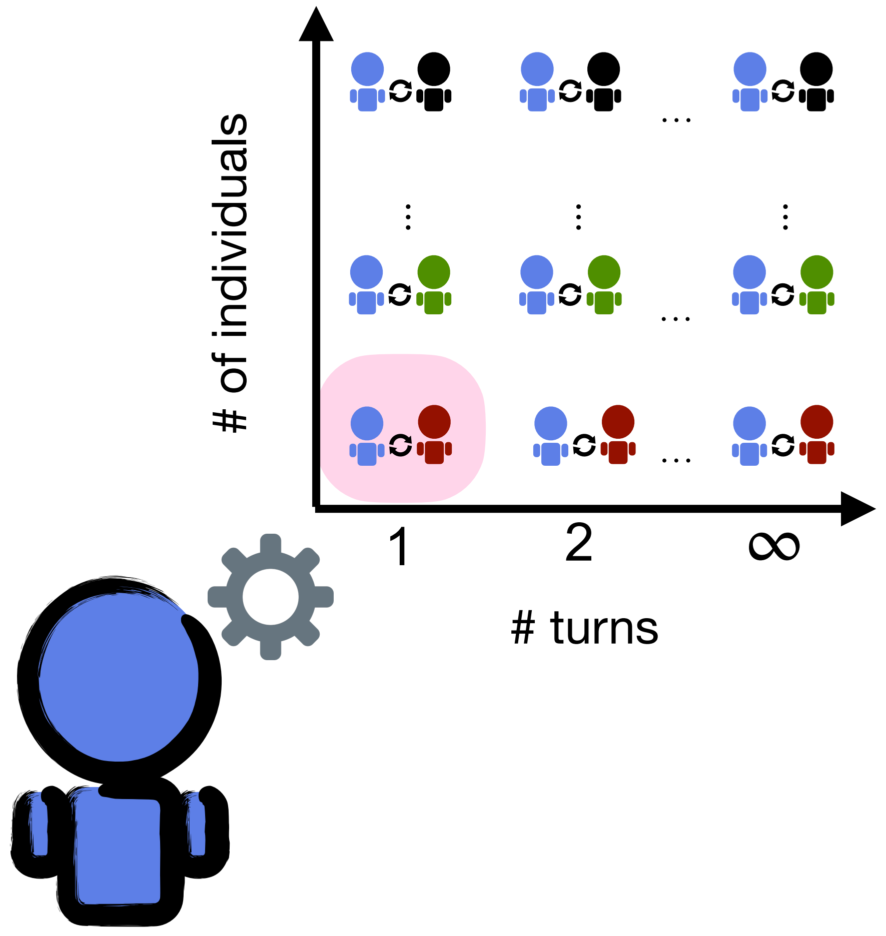

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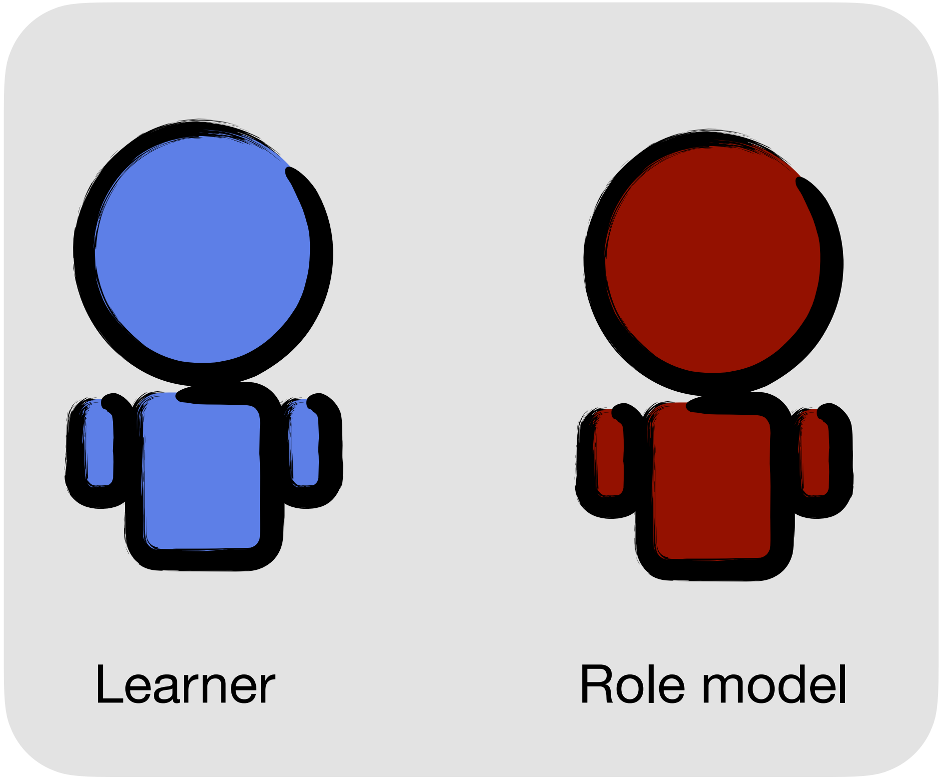

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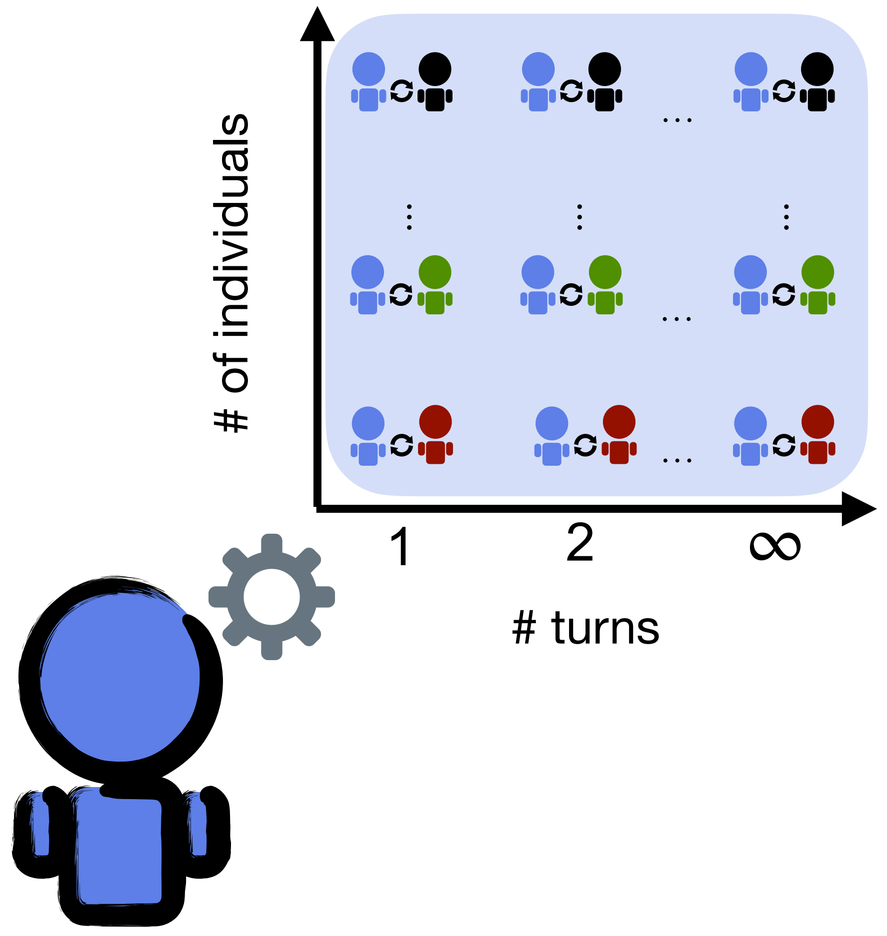

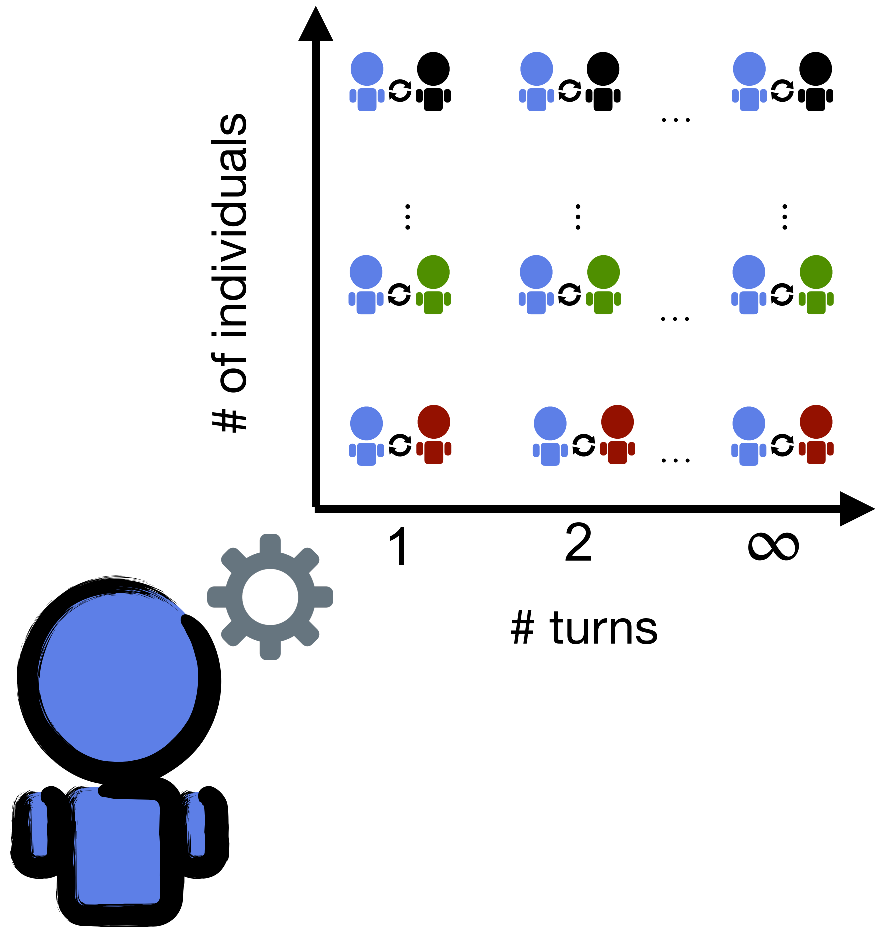

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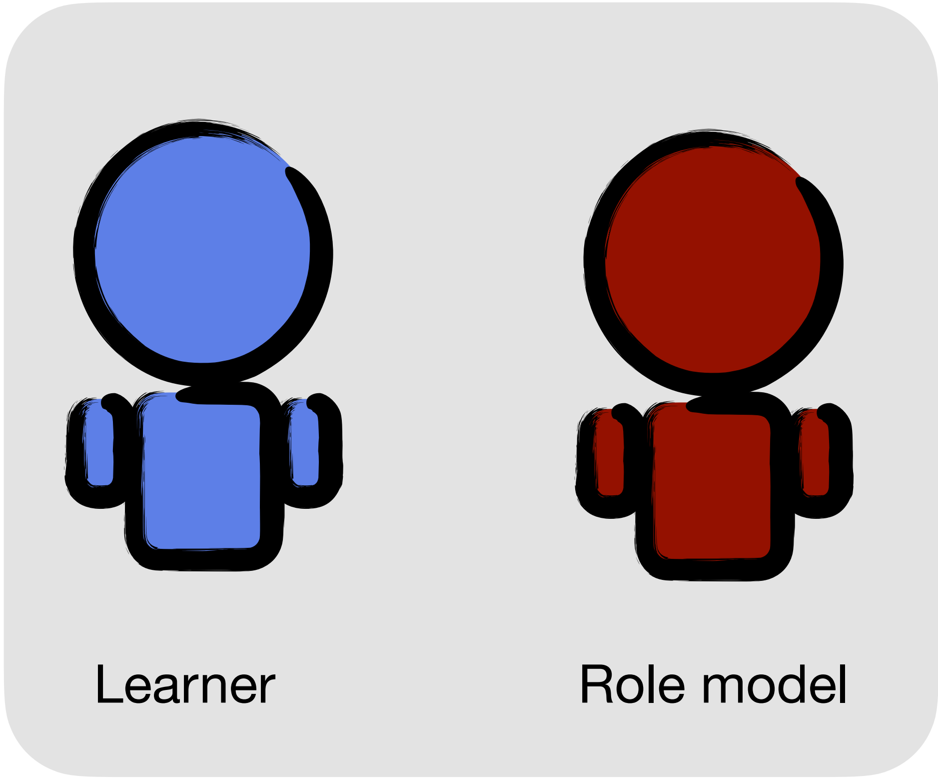

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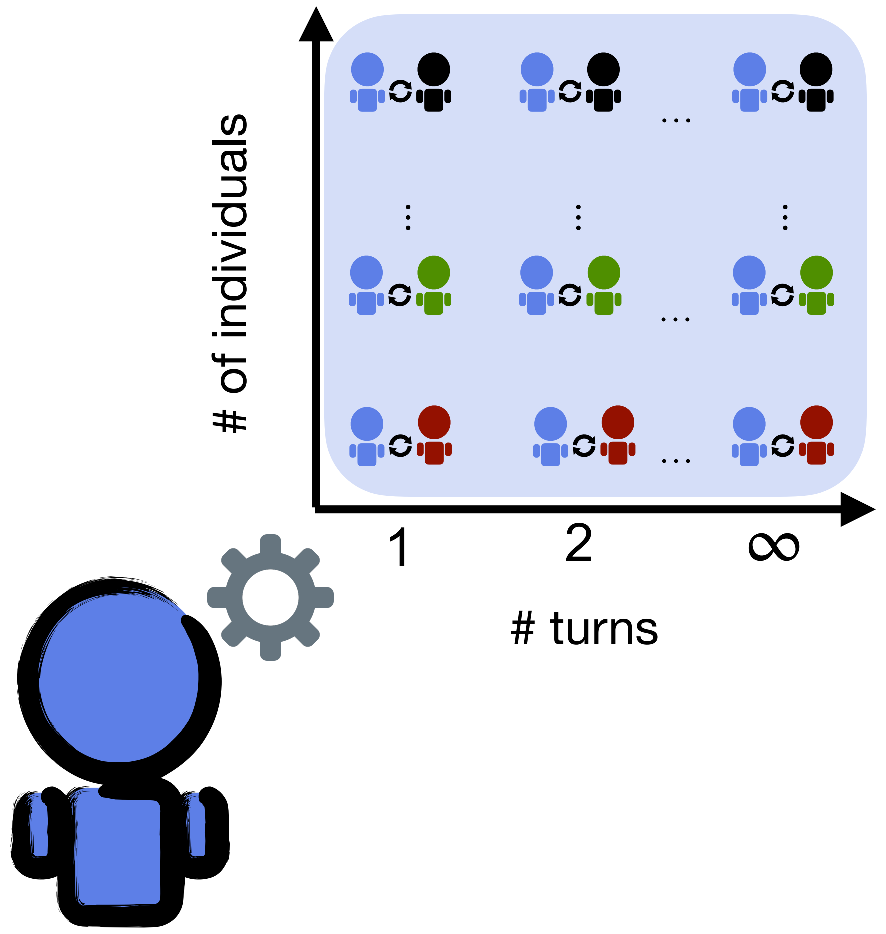

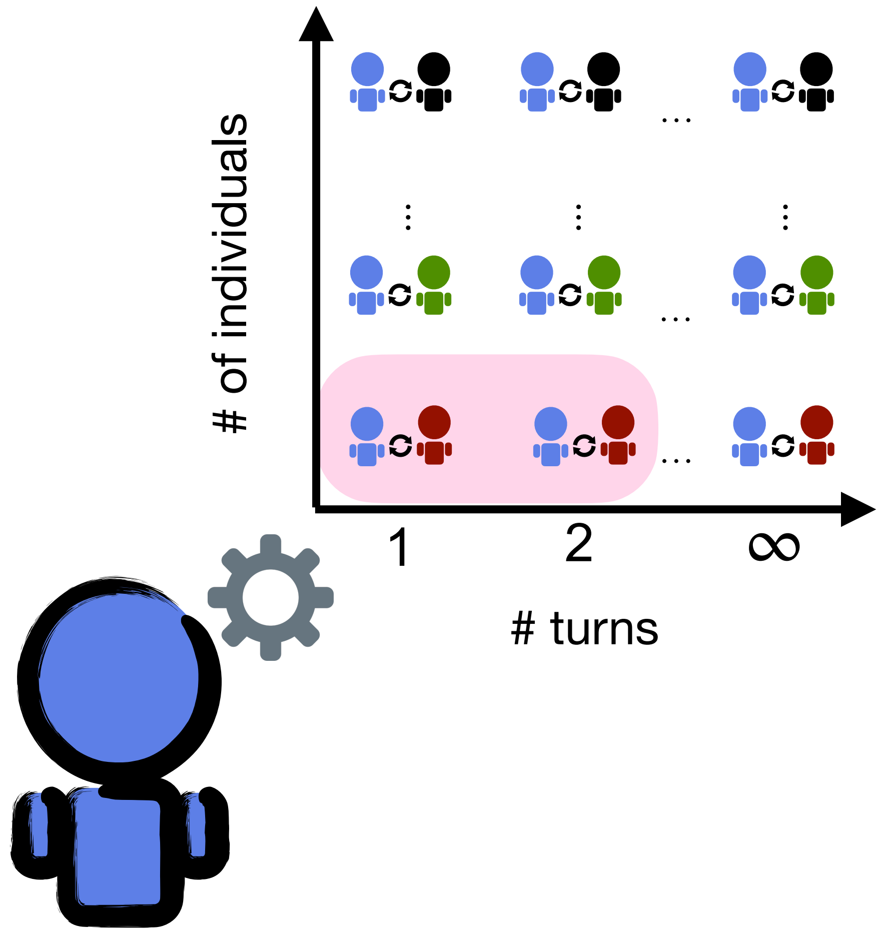

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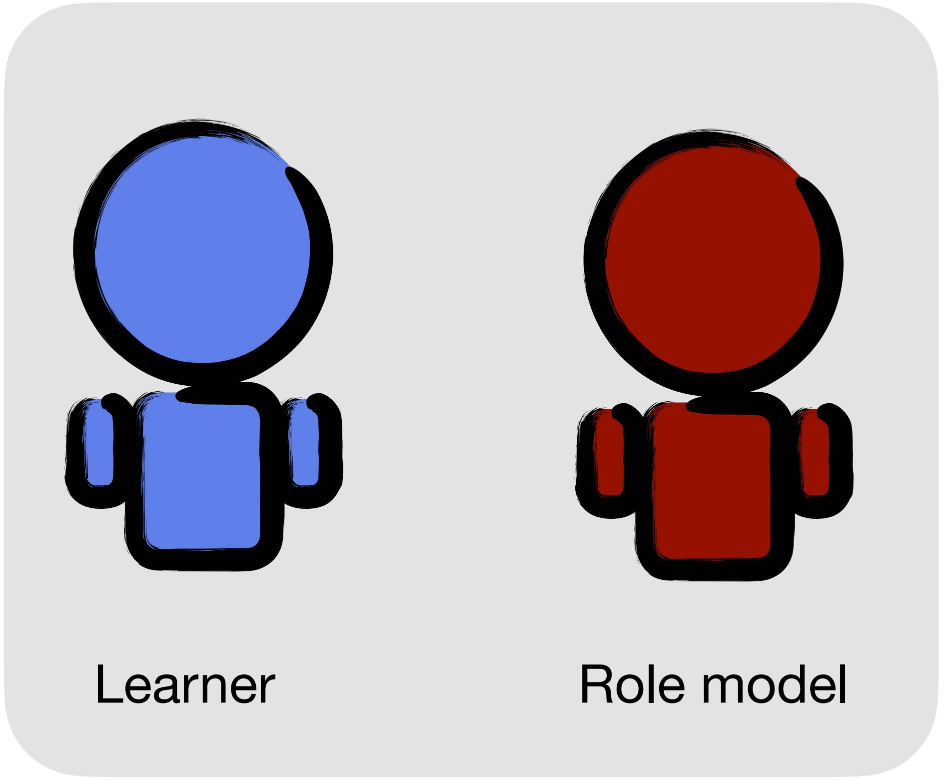

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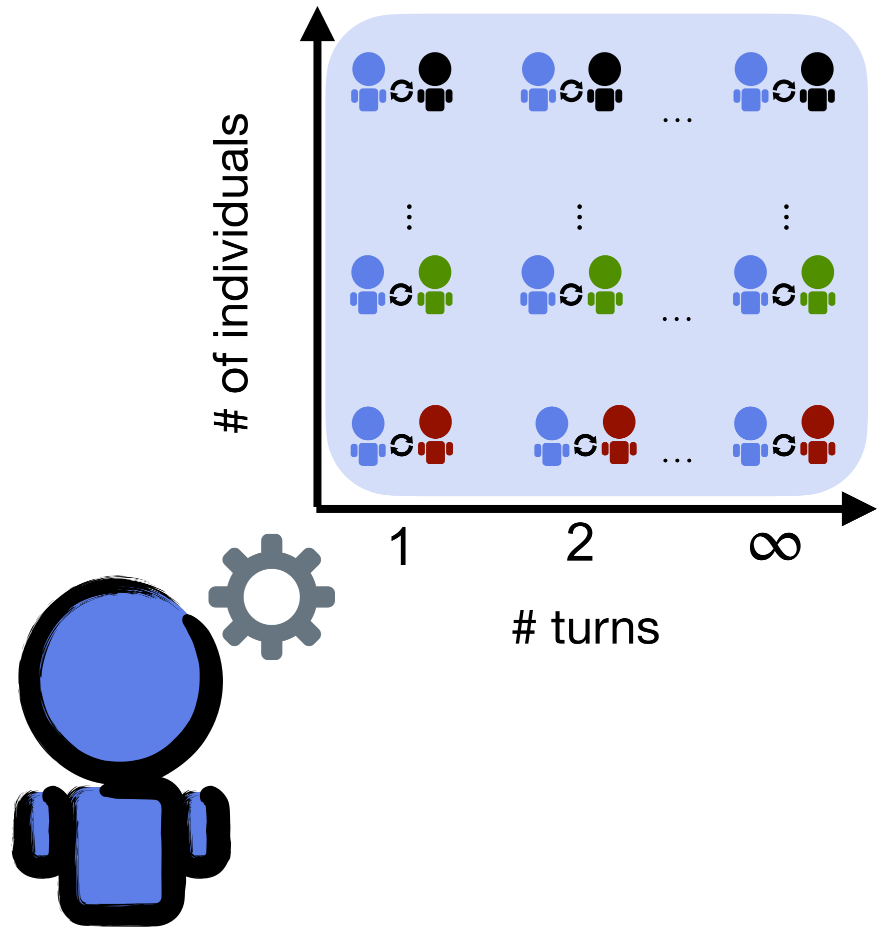

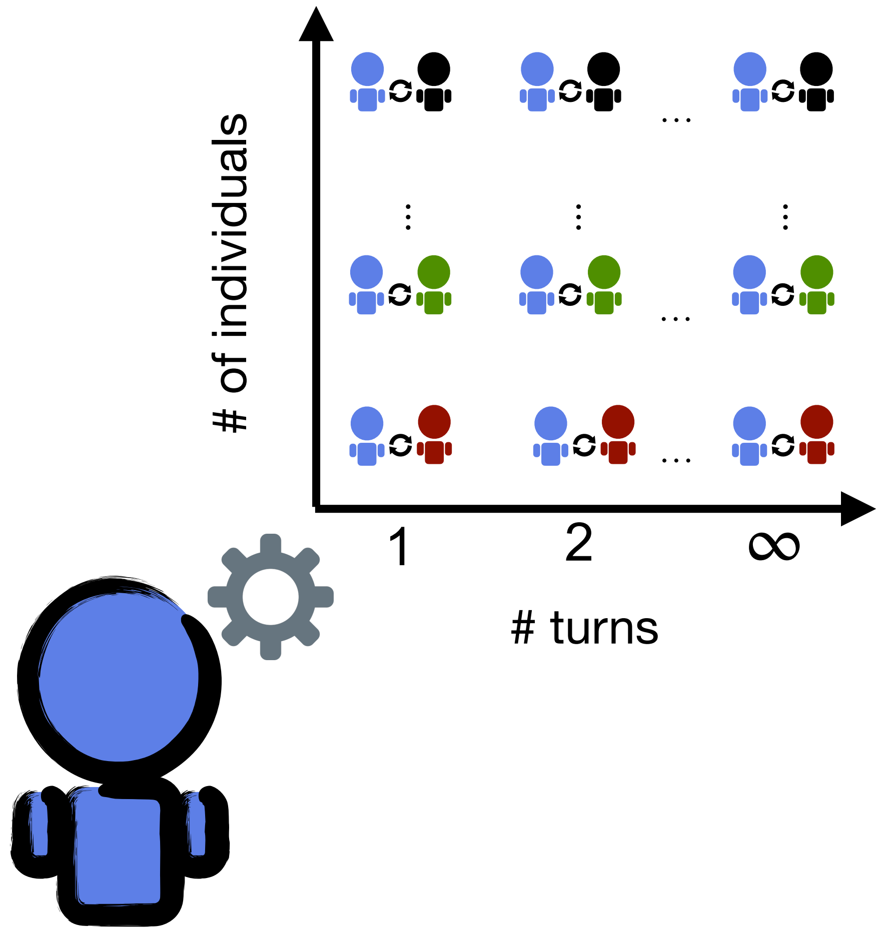

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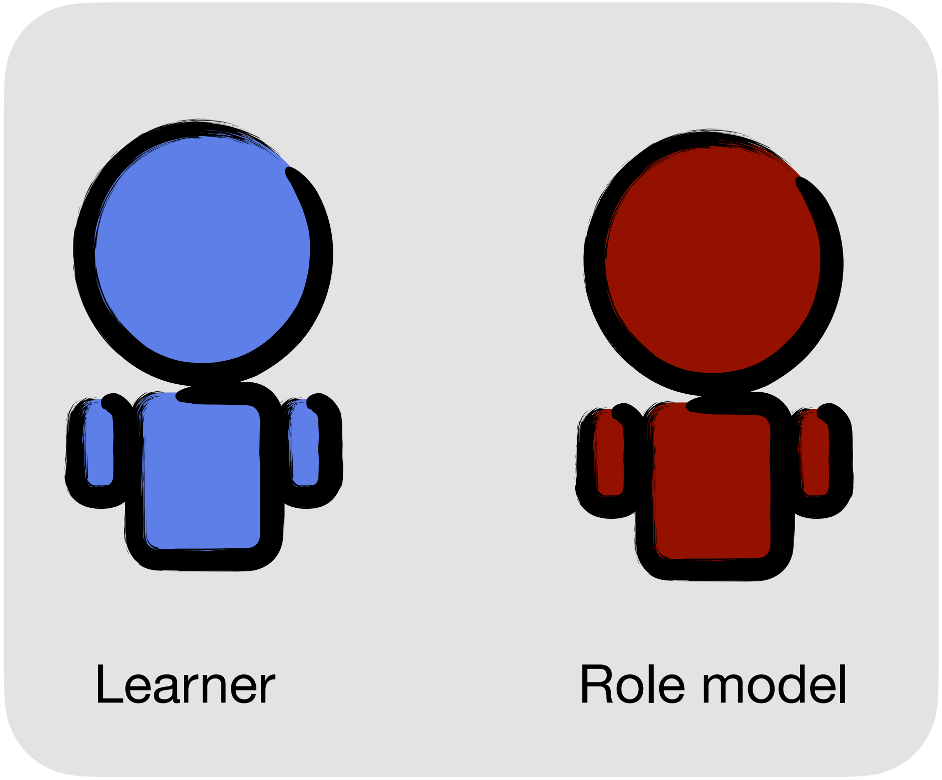

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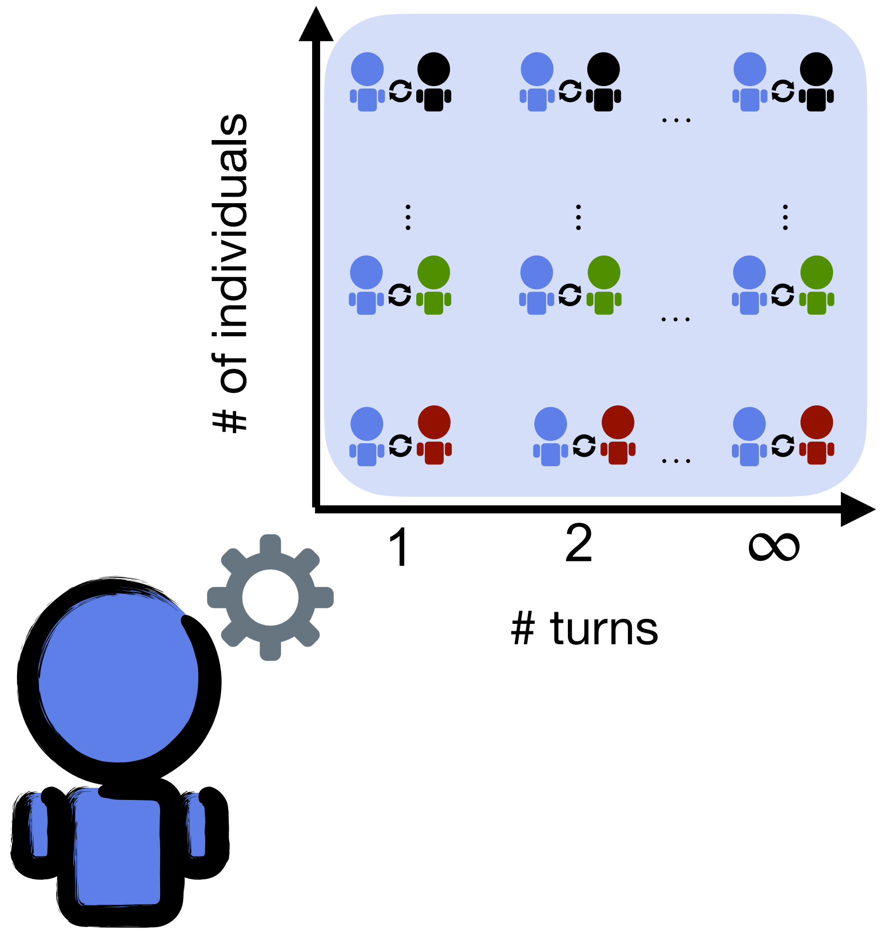

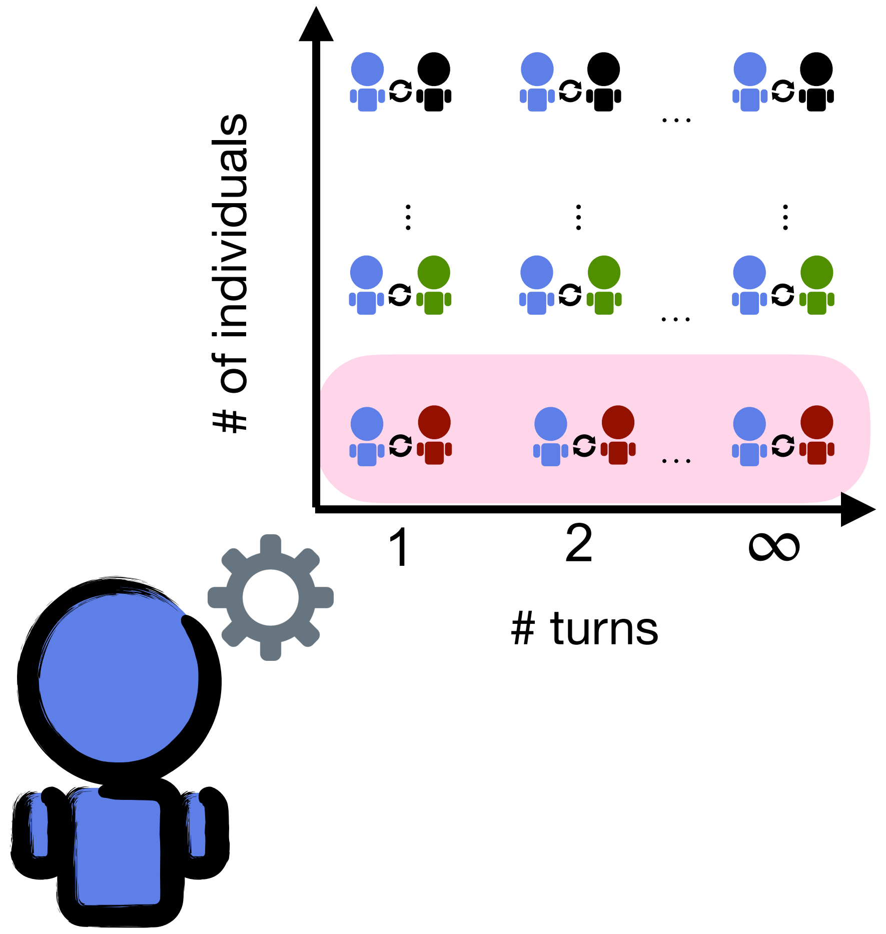

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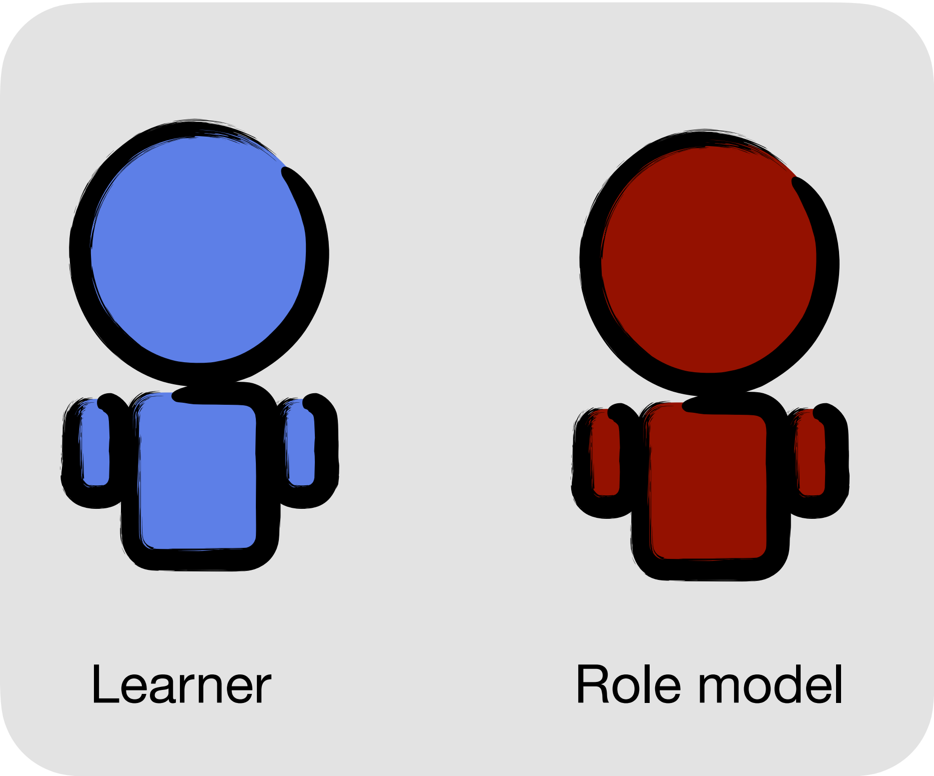

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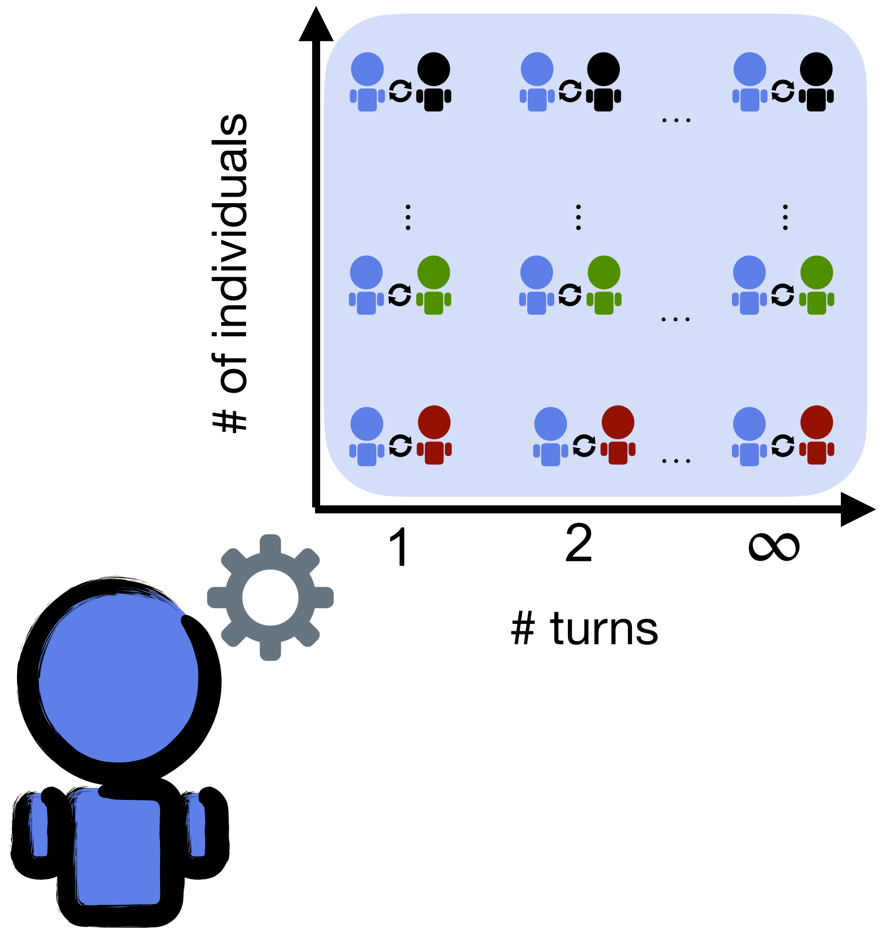

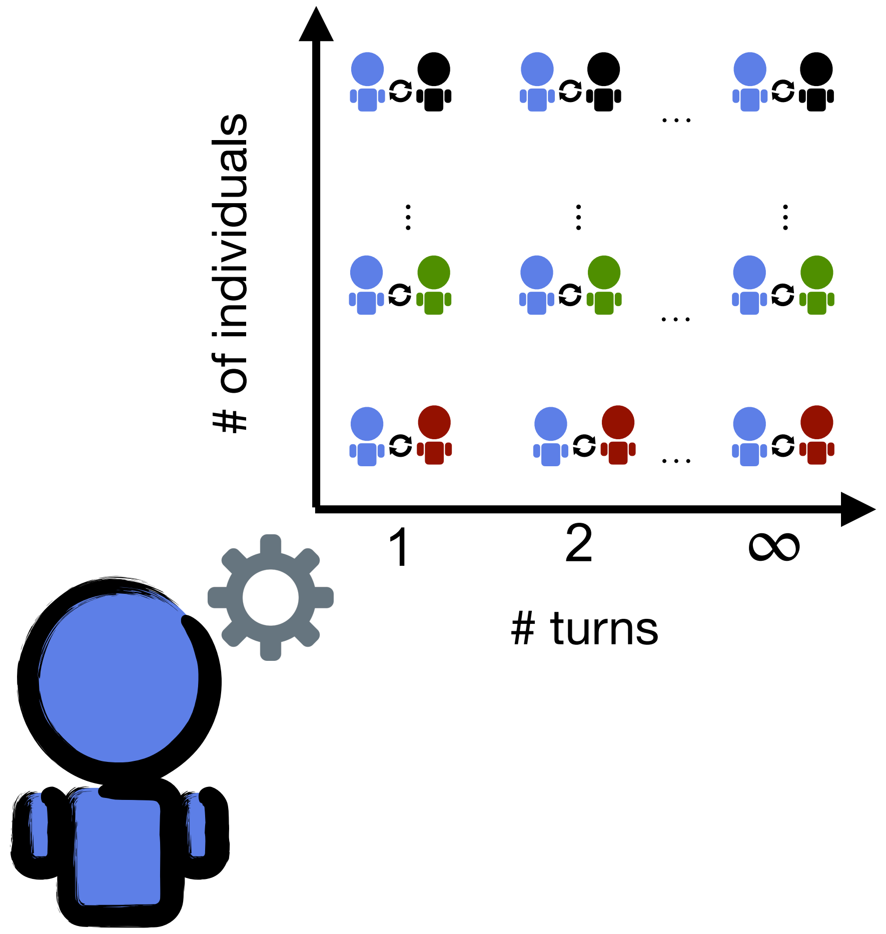

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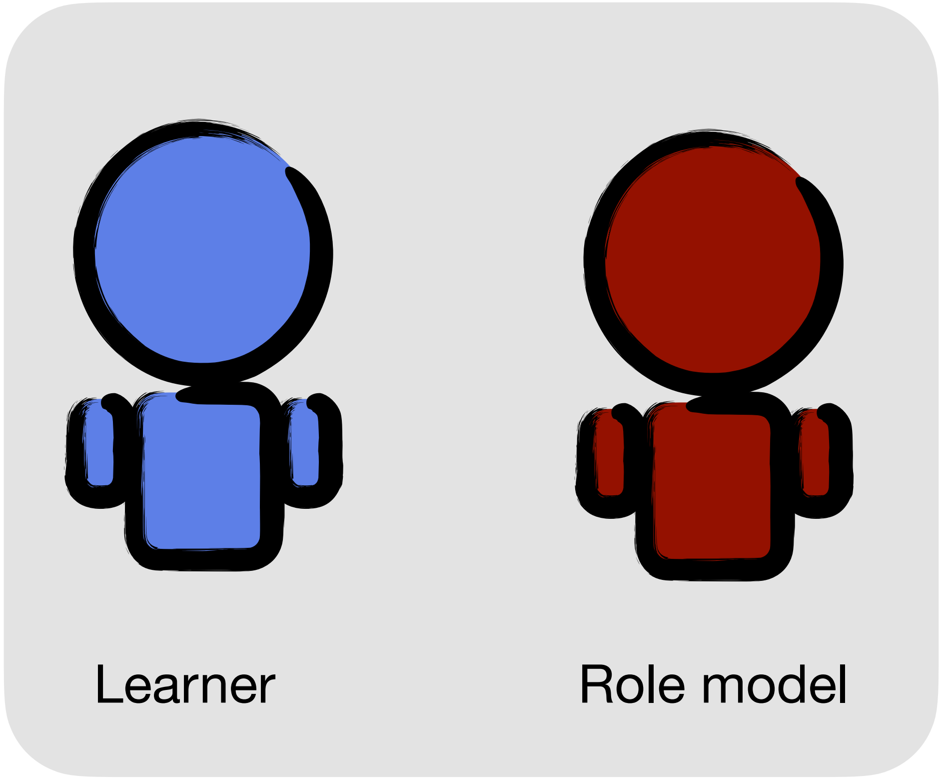

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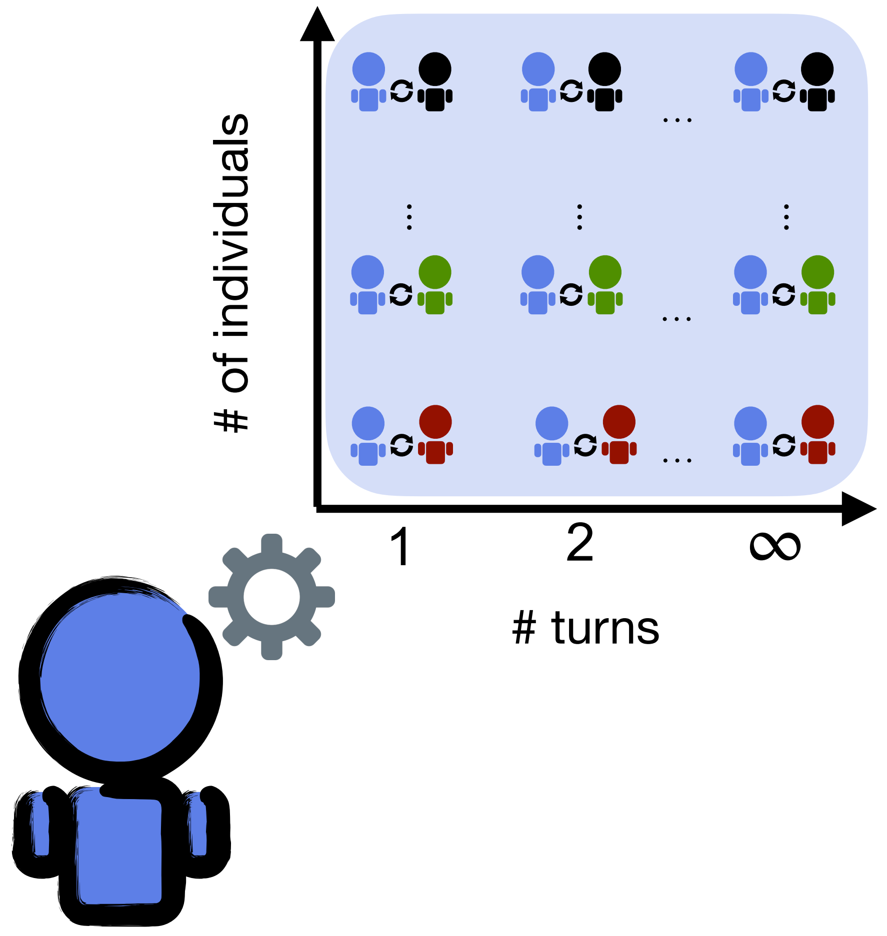

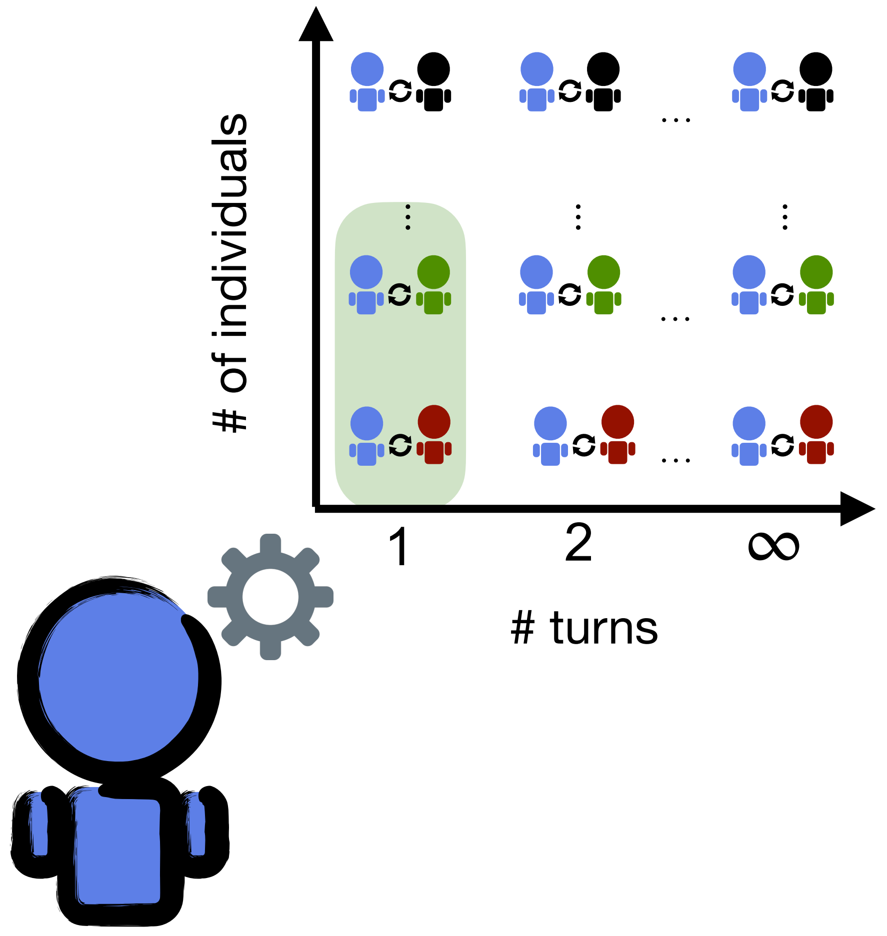

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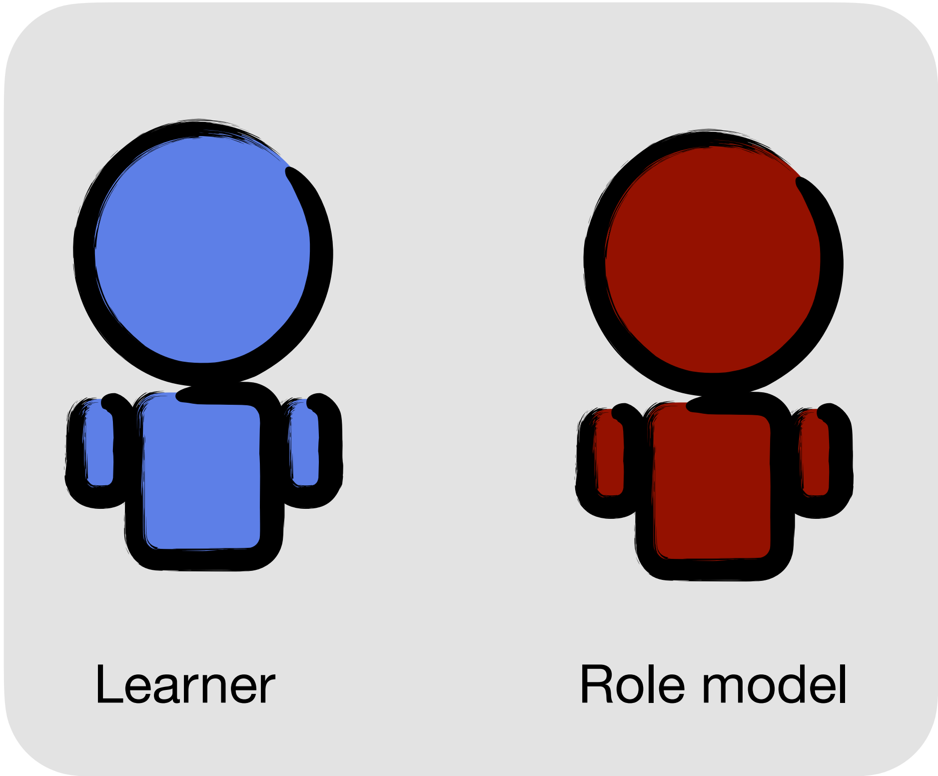

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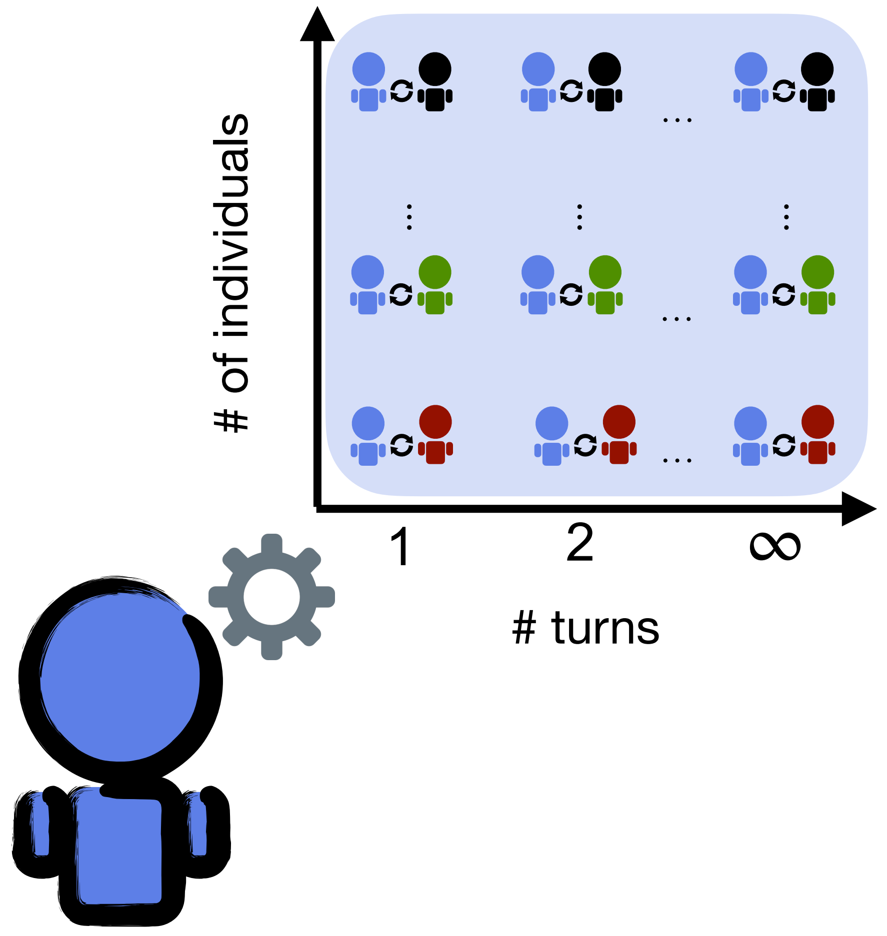

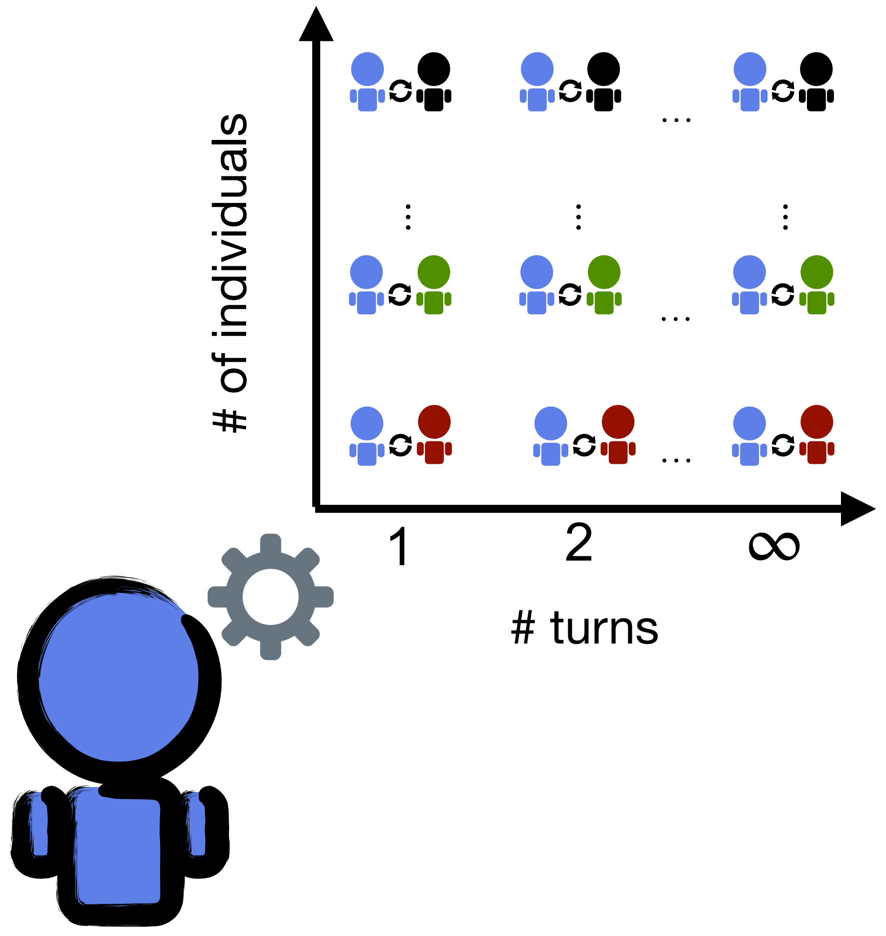

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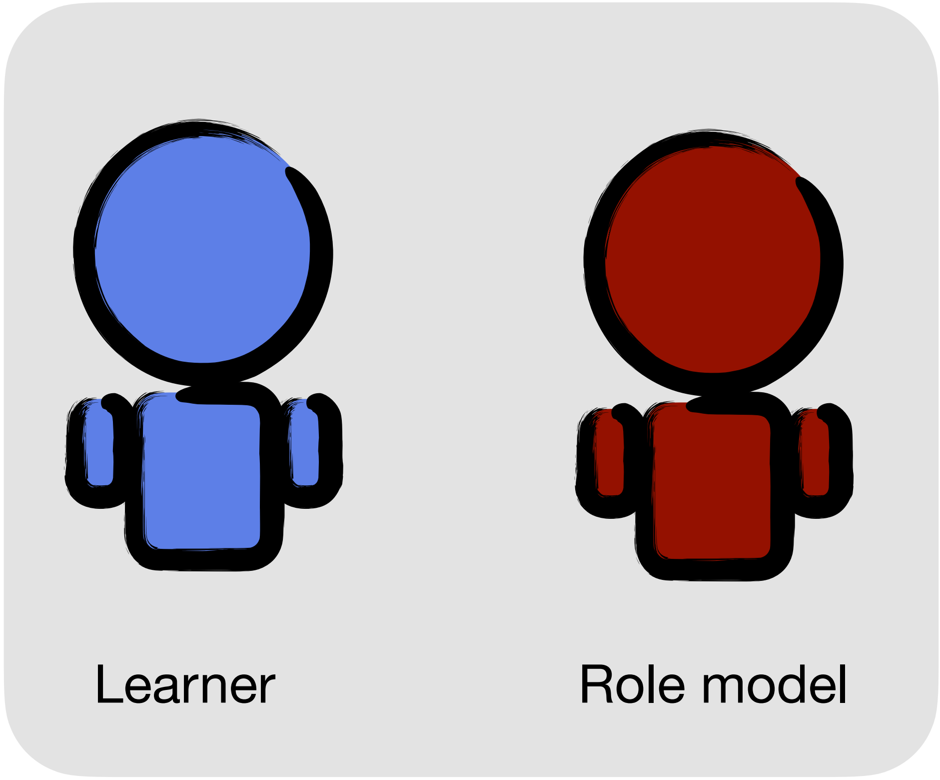

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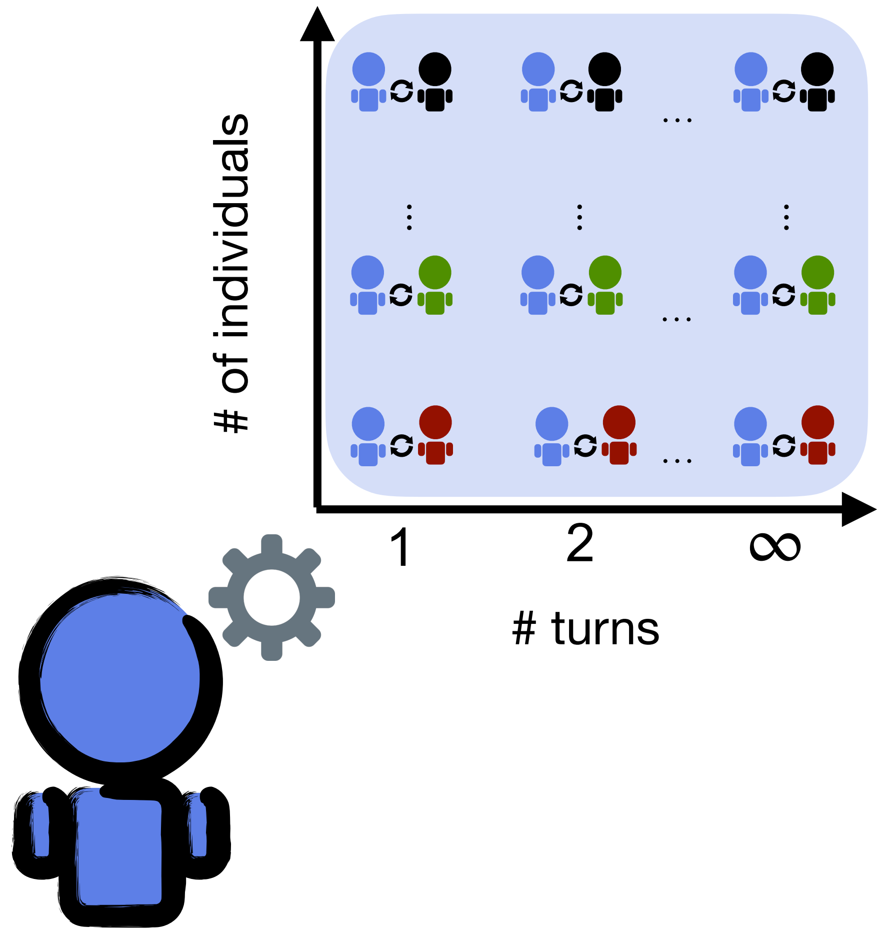

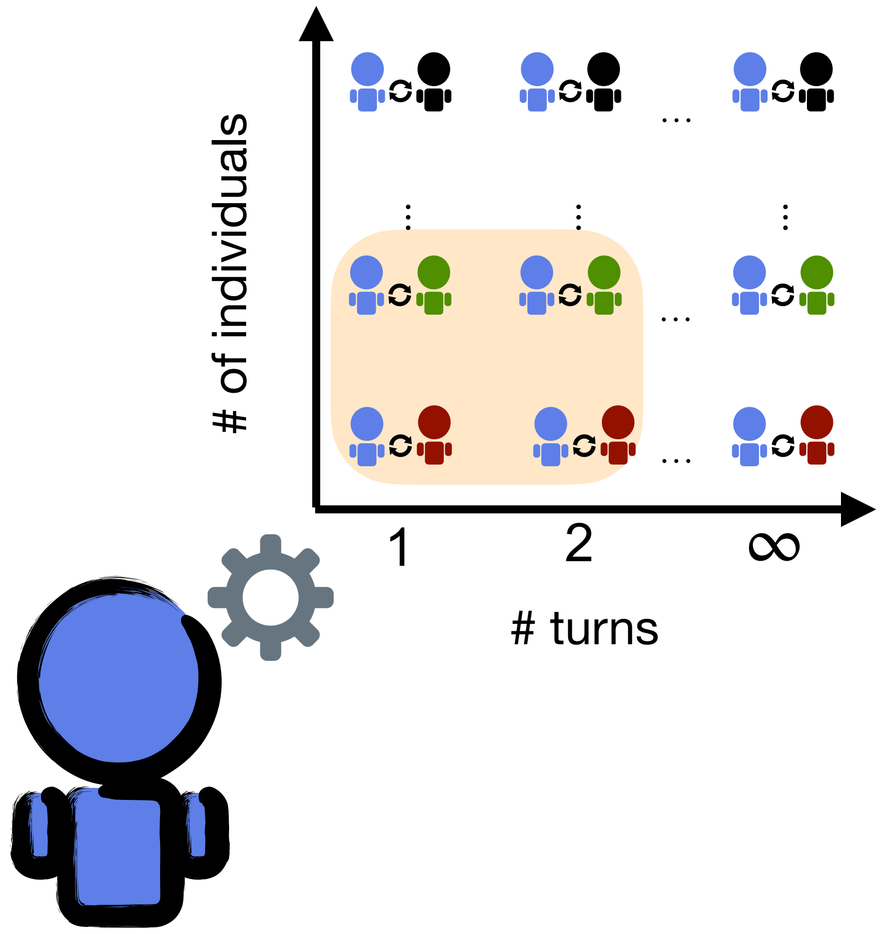

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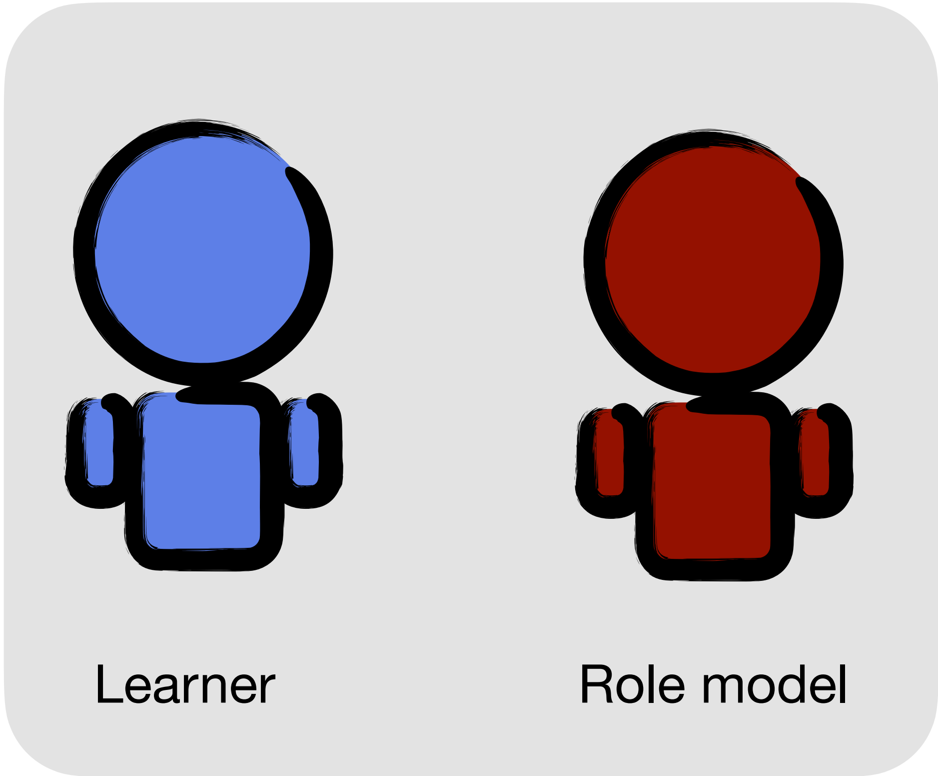

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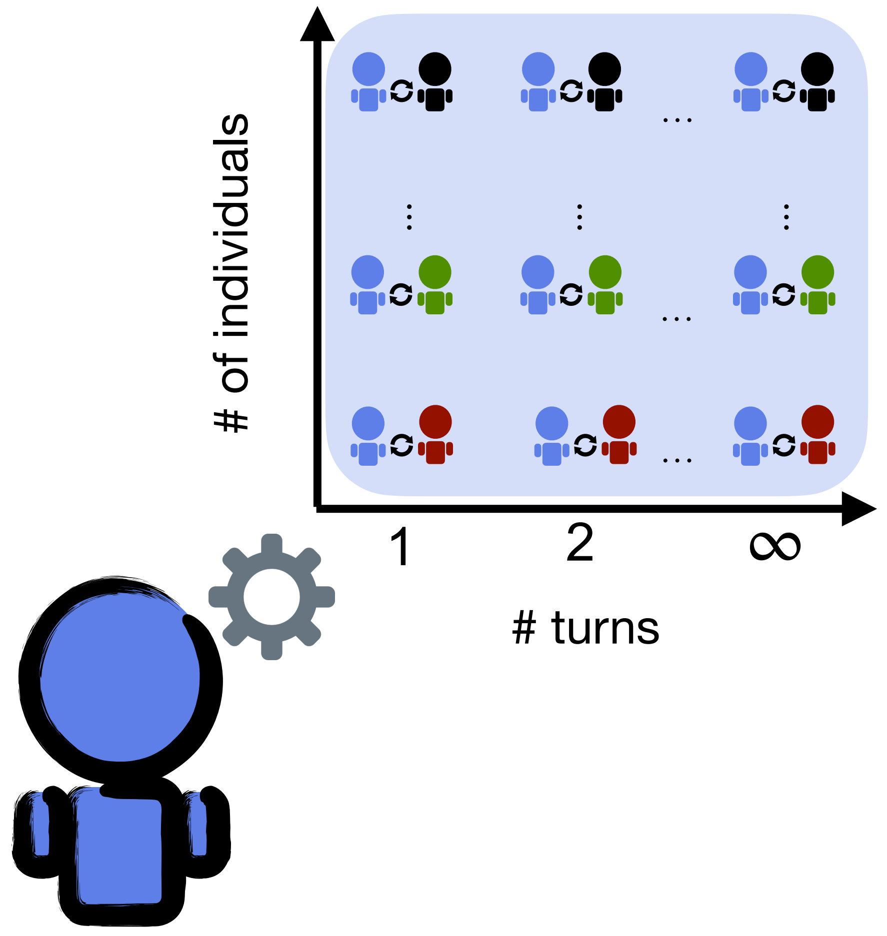

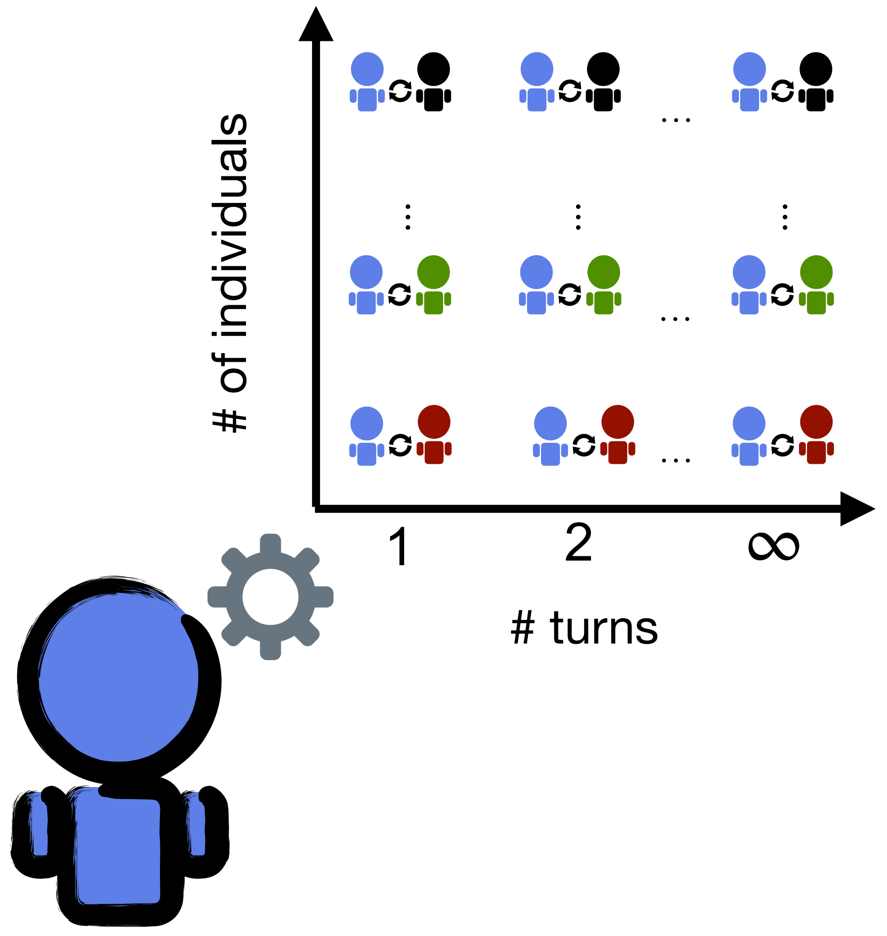

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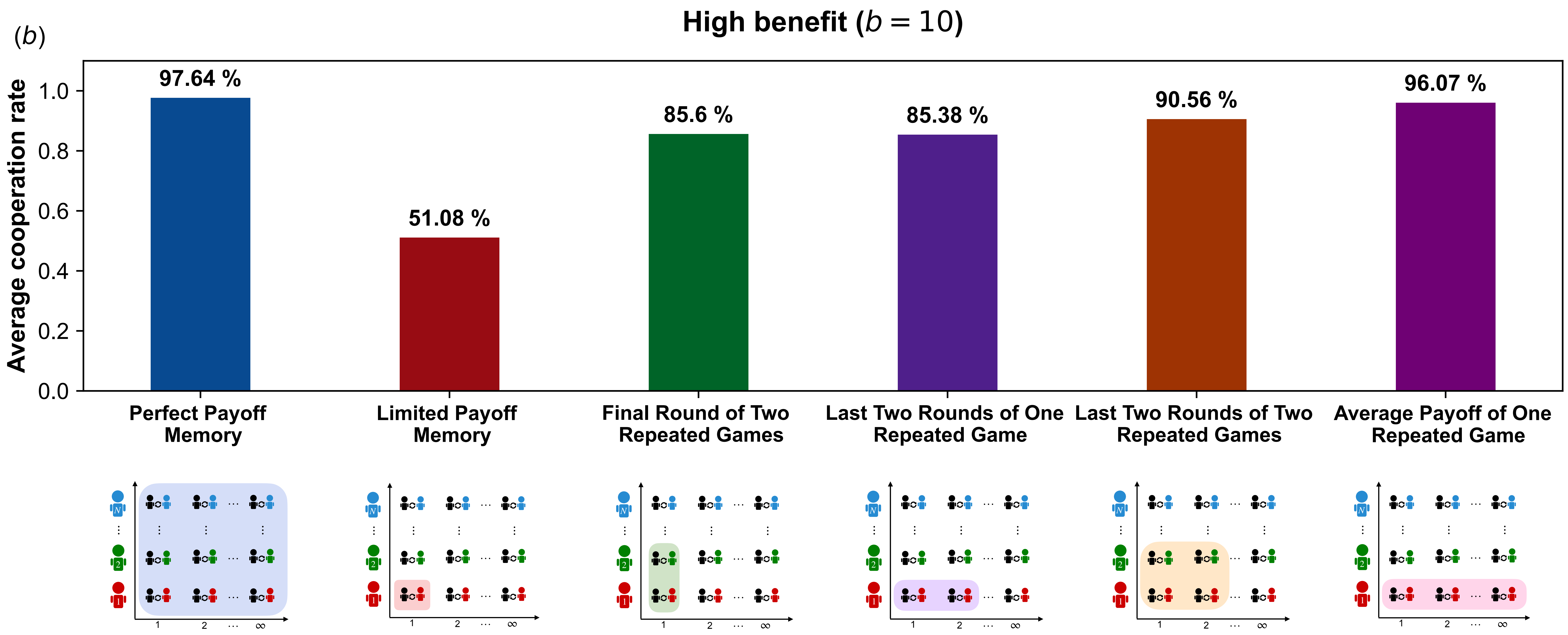

LEARNING IN POPULATIONS

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

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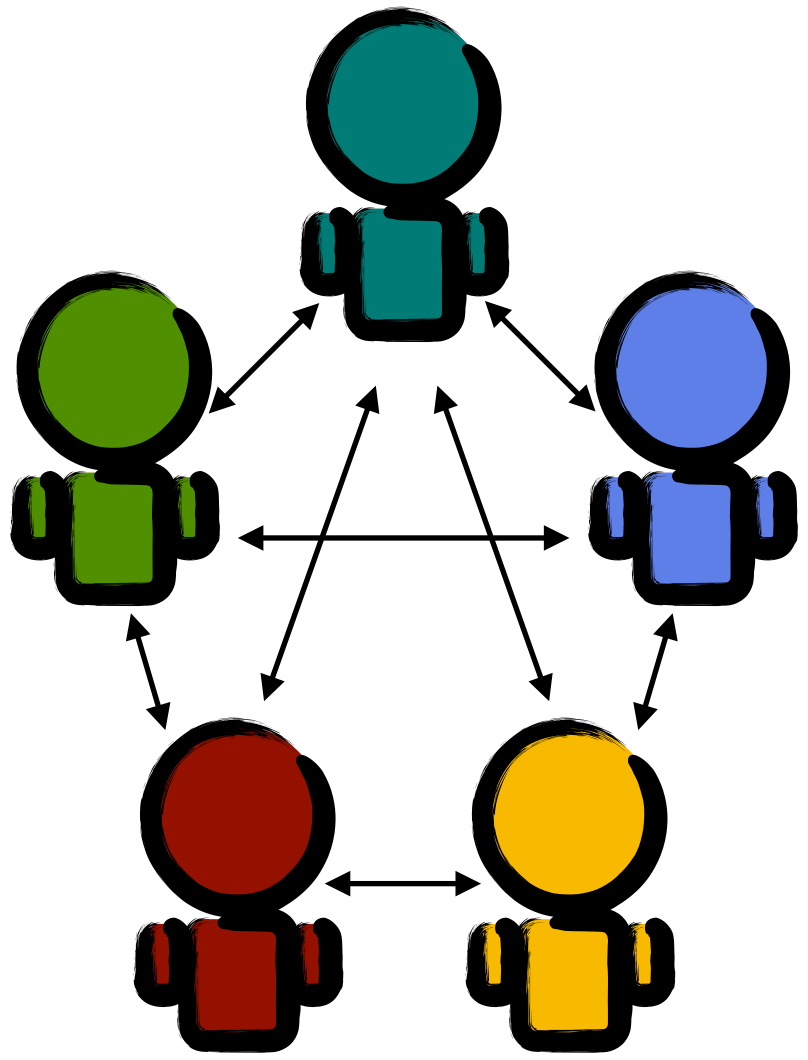
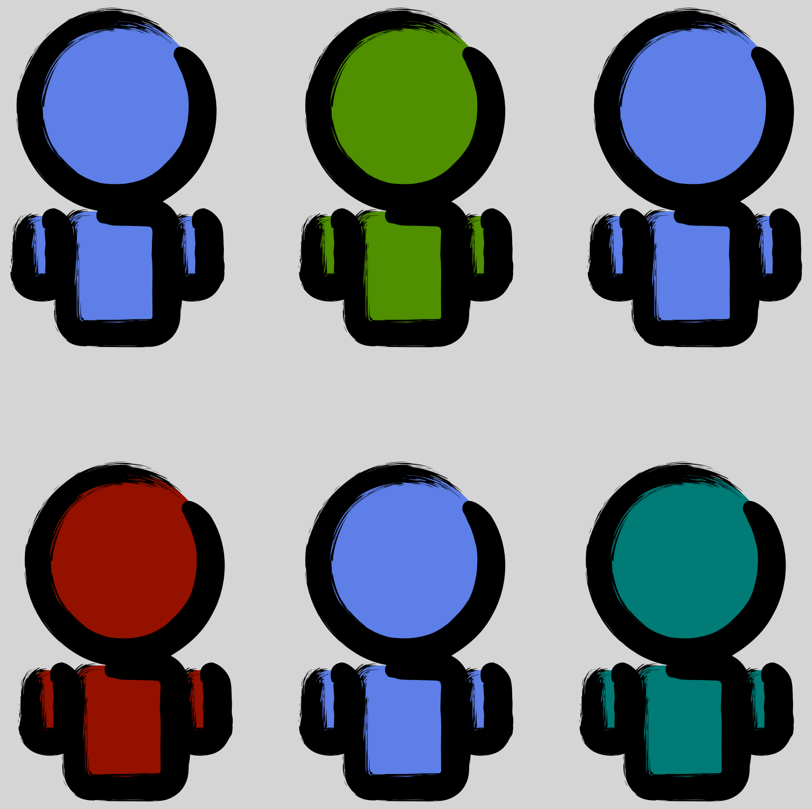
[4] Evolution of reciprocity with limited payoff memory.
https://doi.org/10.1098/rspb.2023.2493

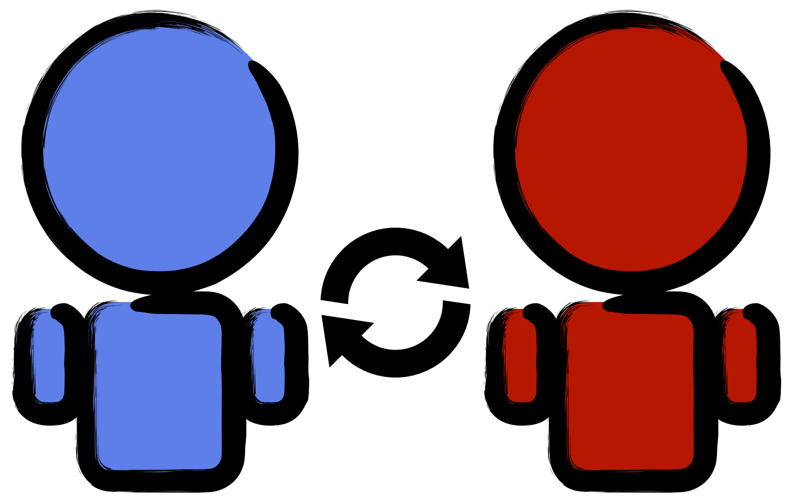
Strategies in computer tournaments



Learning in populations



Strategies in repeated interactions



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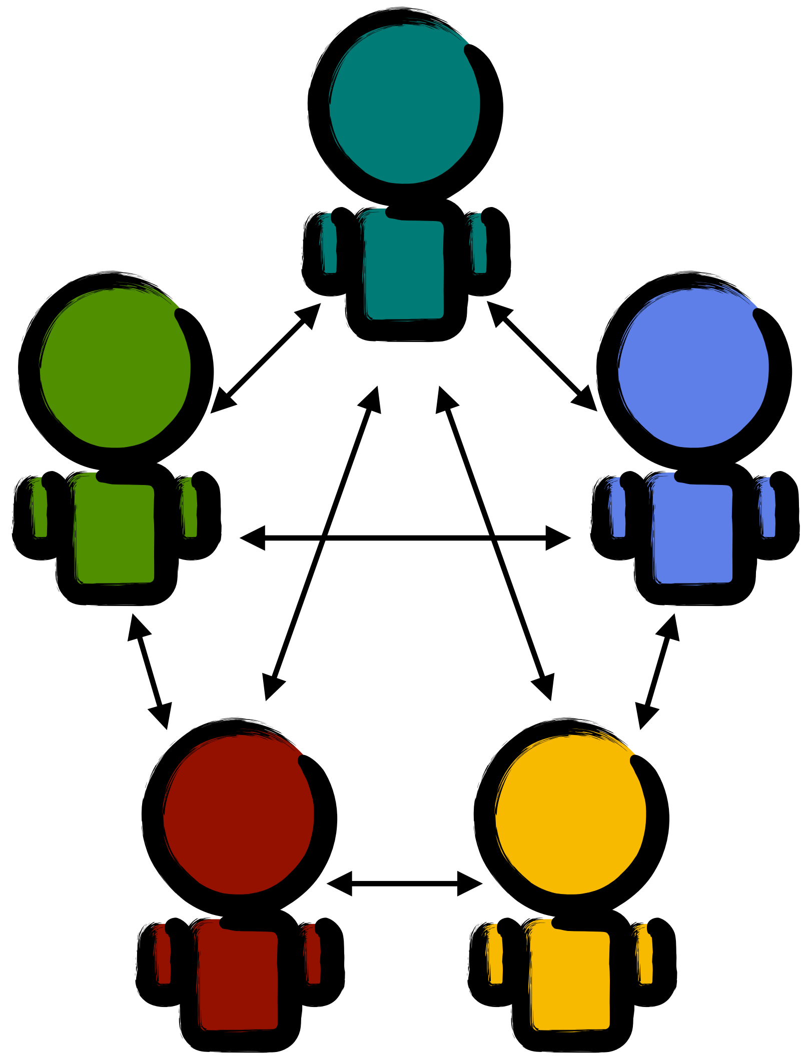

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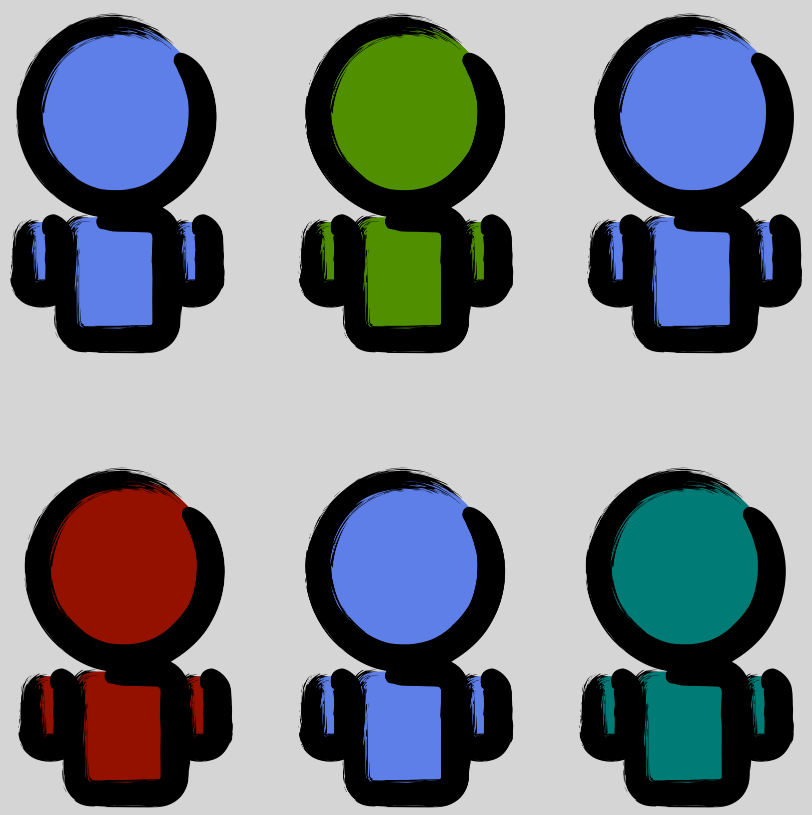

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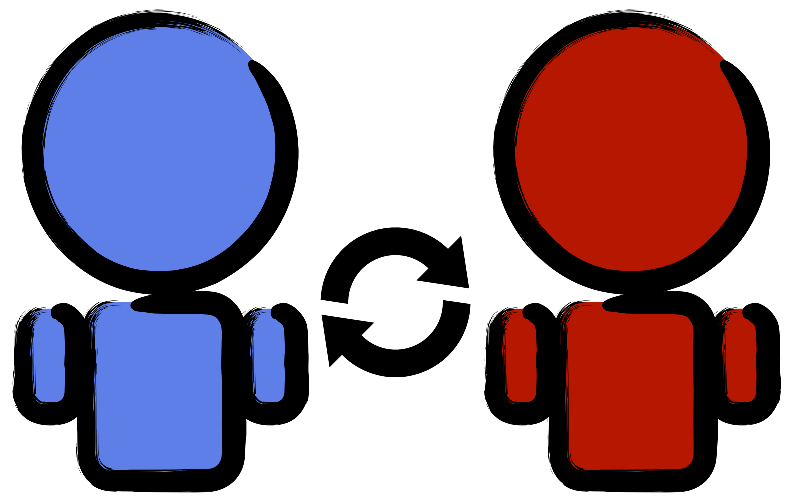
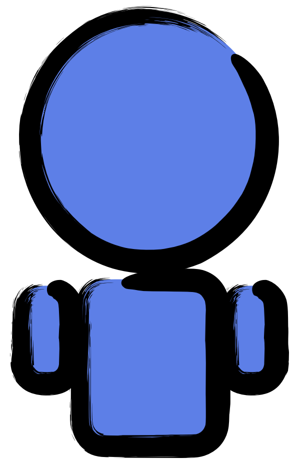
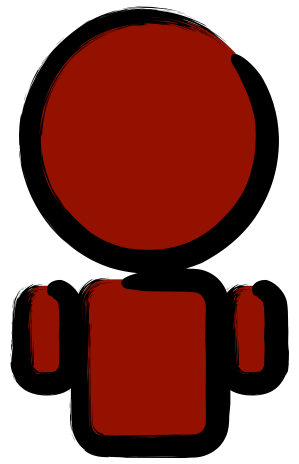


STRATEGIES IN REPEATED GAMES

$$\begin{pmatrix} b-c & -c \\ b & 0 \end{pmatrix} \quad \begin{pmatrix} b-c & -c \\ b & 0 \end{pmatrix} \quad \begin{pmatrix} b-c & -c \\ b & 0 \end{pmatrix} \quad \begin{pmatrix} b-c & -c \\ b & 0 \end{pmatrix}$$



$D \quad C \quad C$



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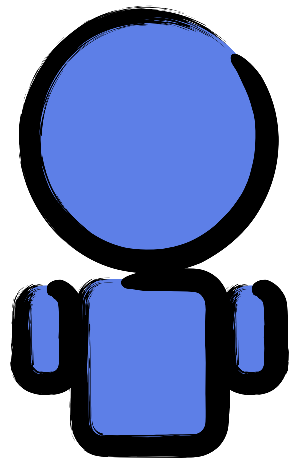

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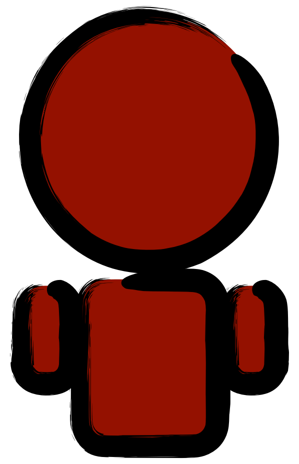

D D C

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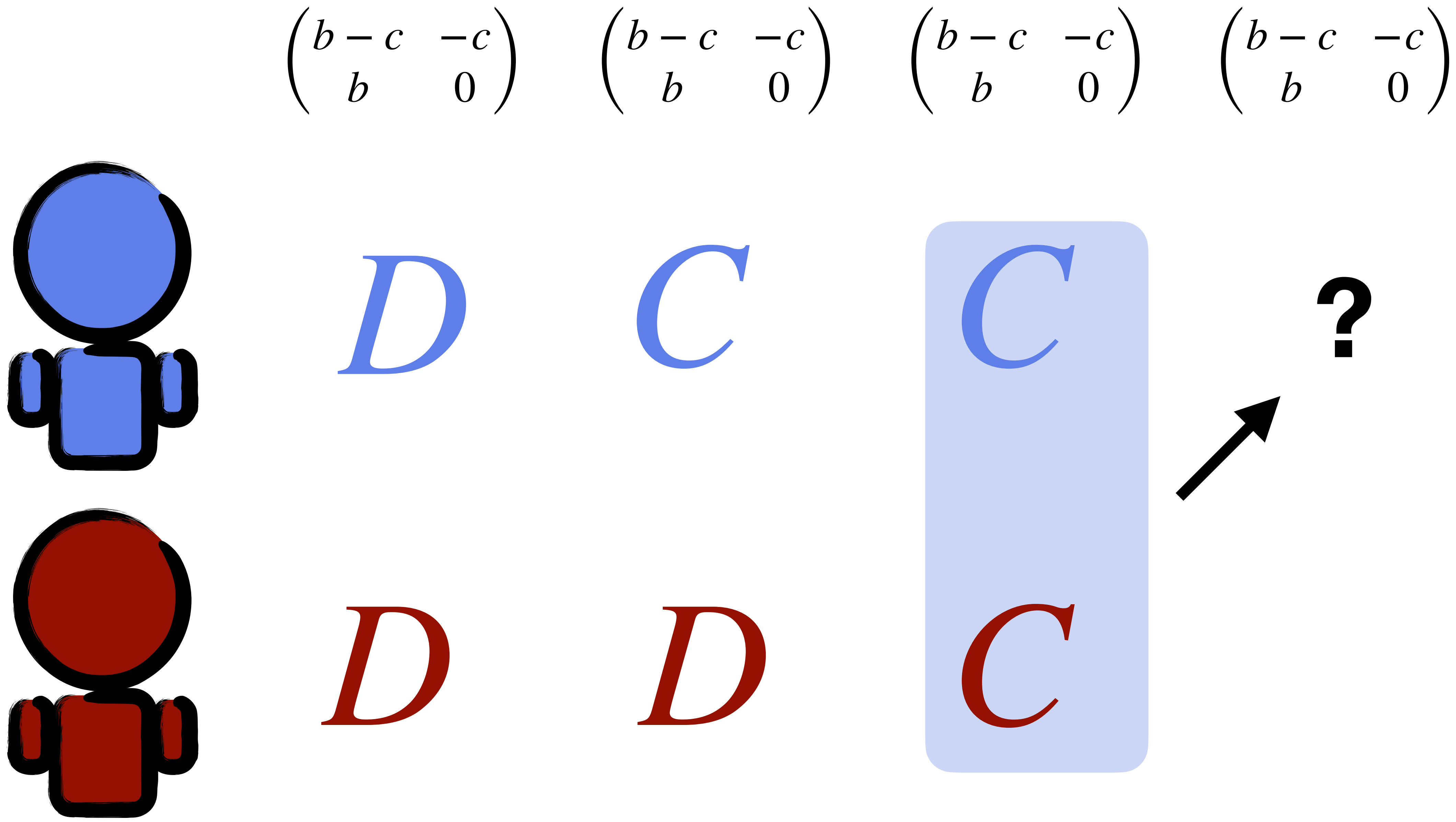

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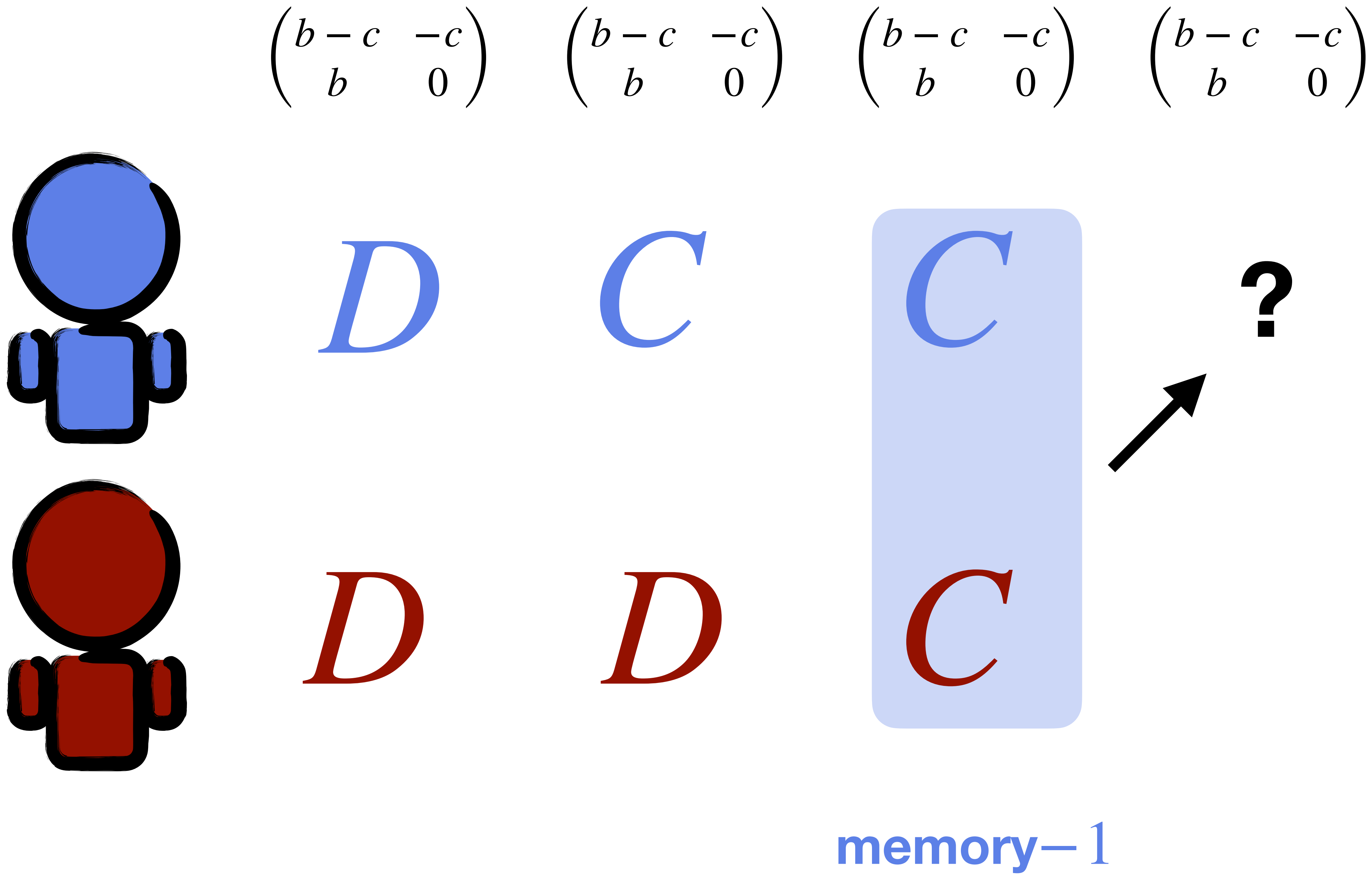

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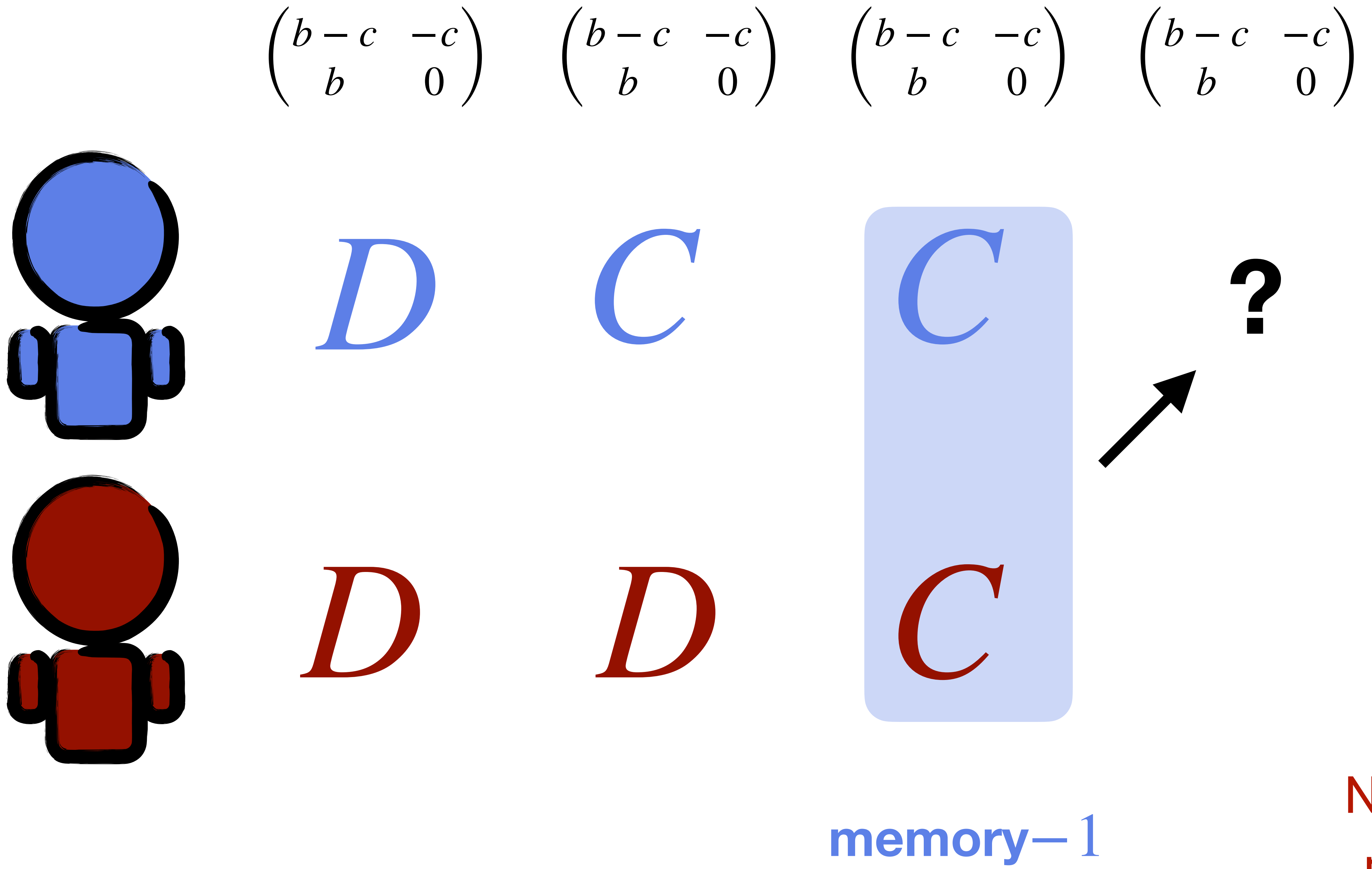
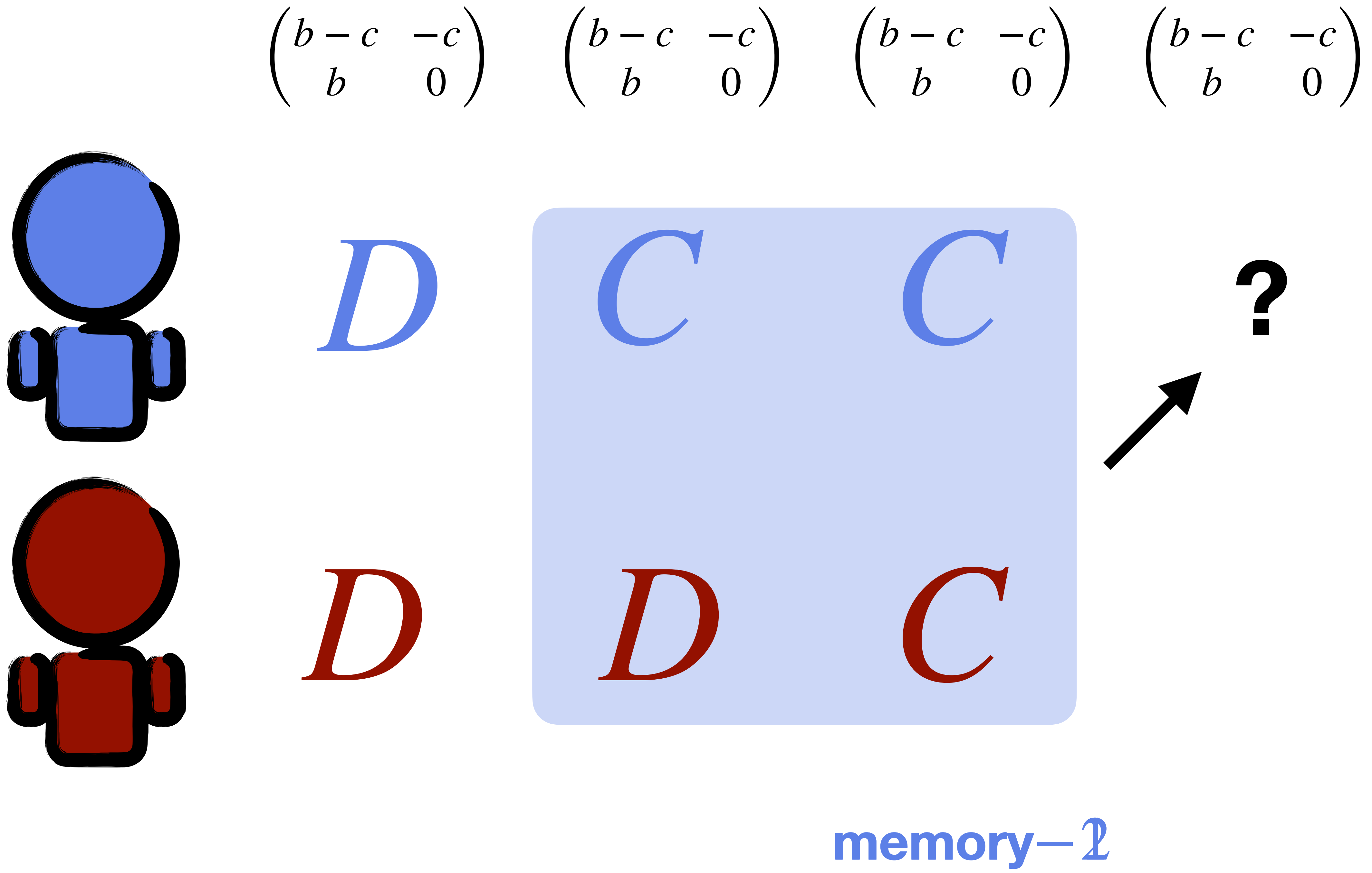


Nash equilibria among
memory-1 strategies

STRATEGIES IN REPEATED GAMES



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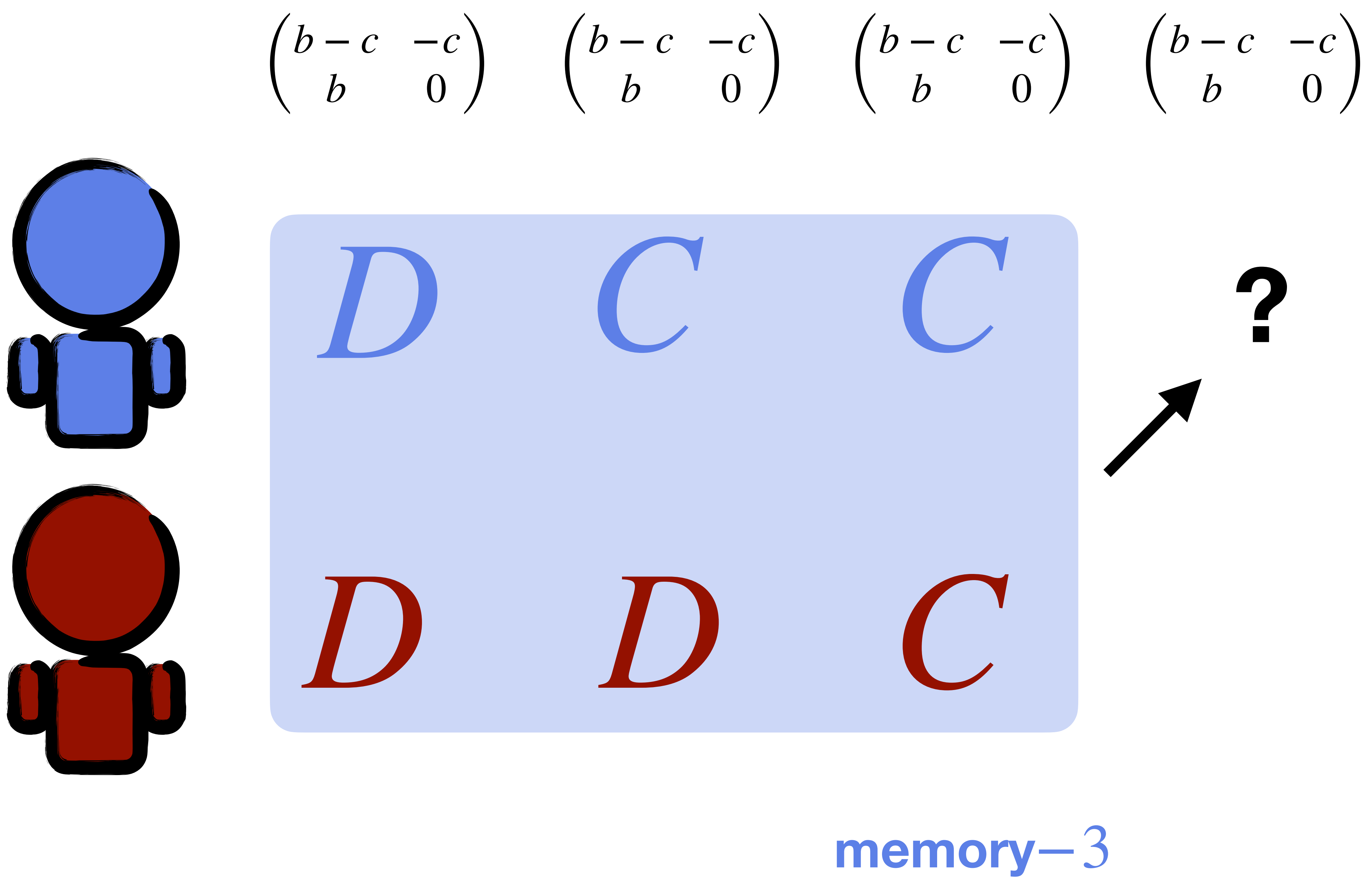

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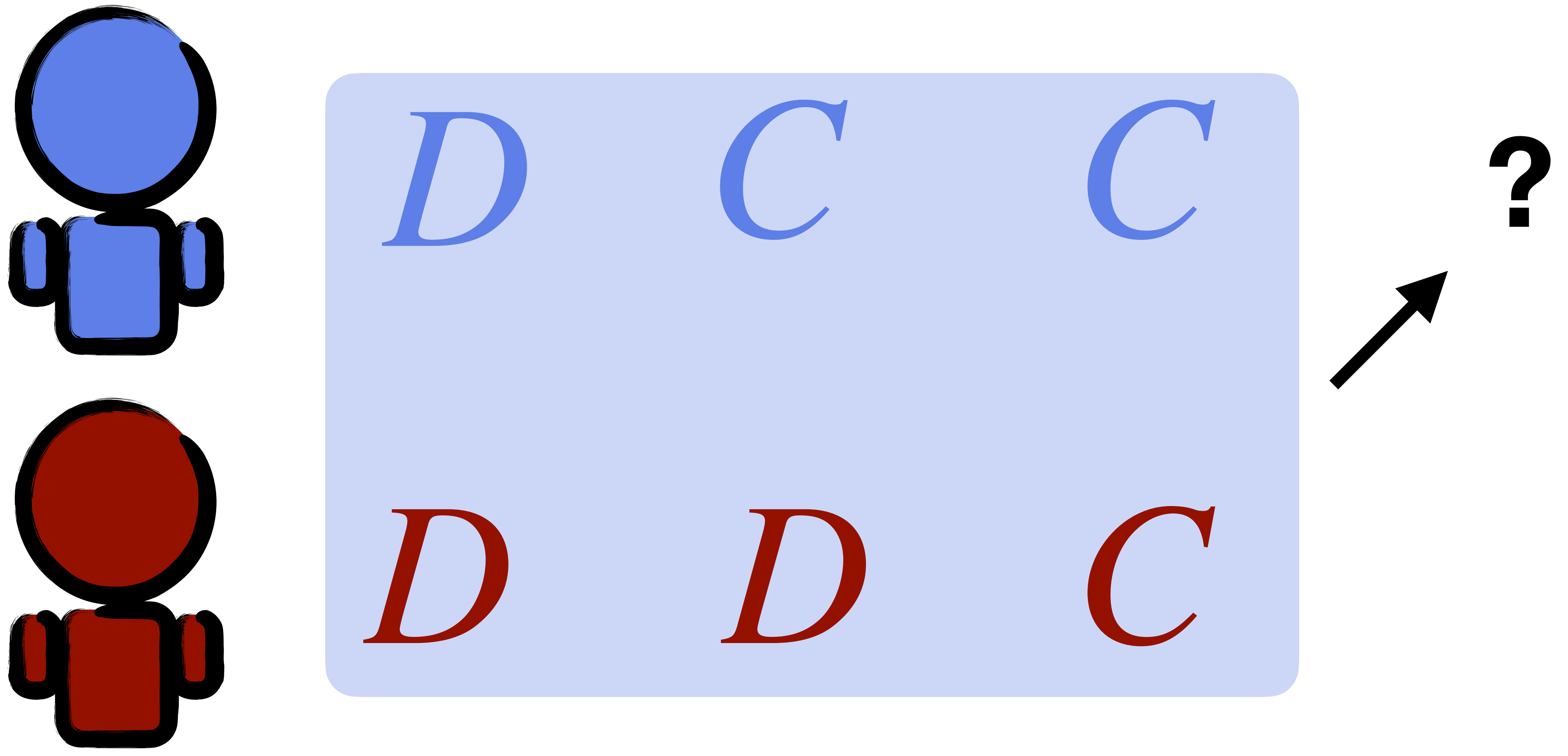
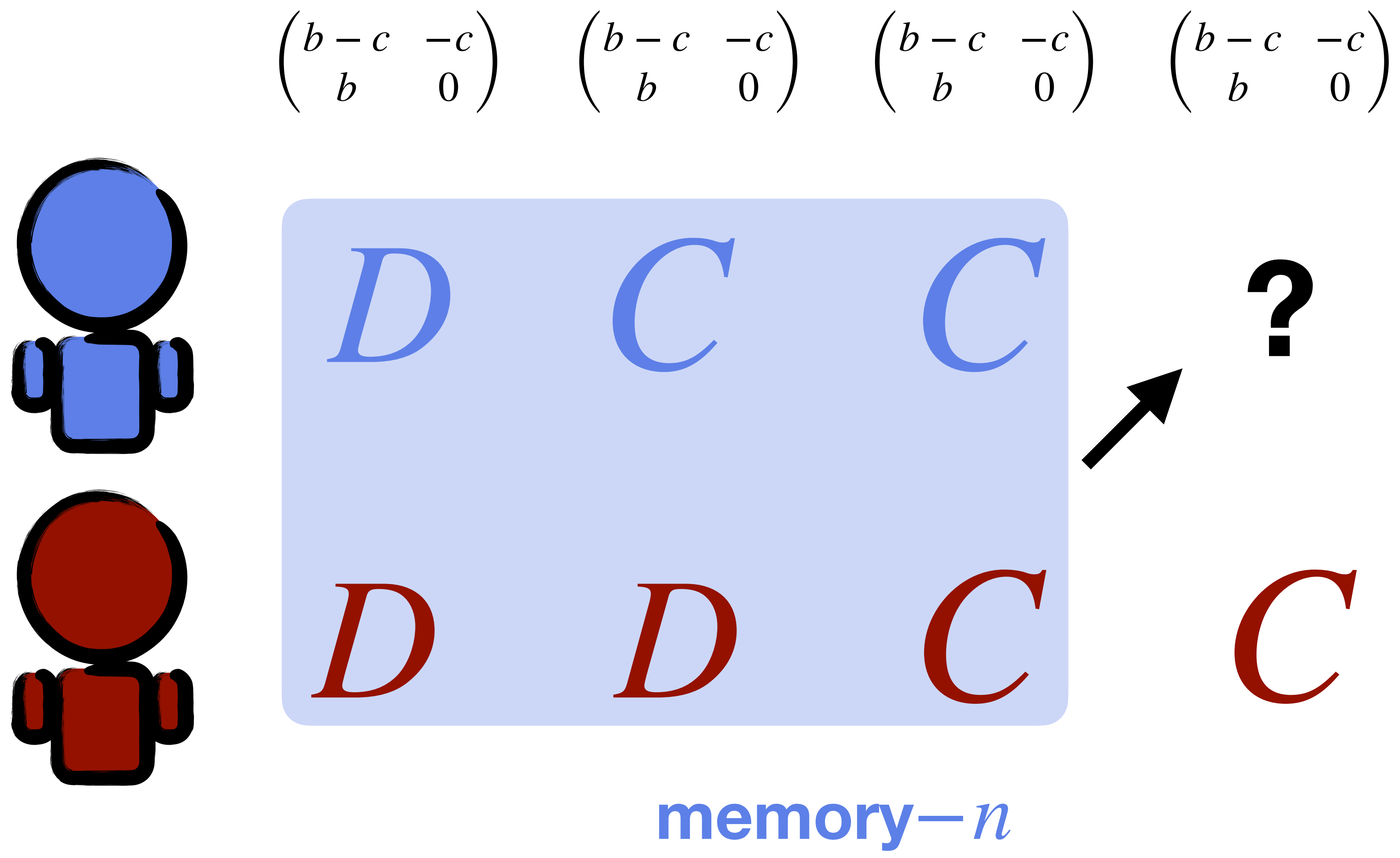


memory$-n$

STRATEGIES IN REPEATED GAMES

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



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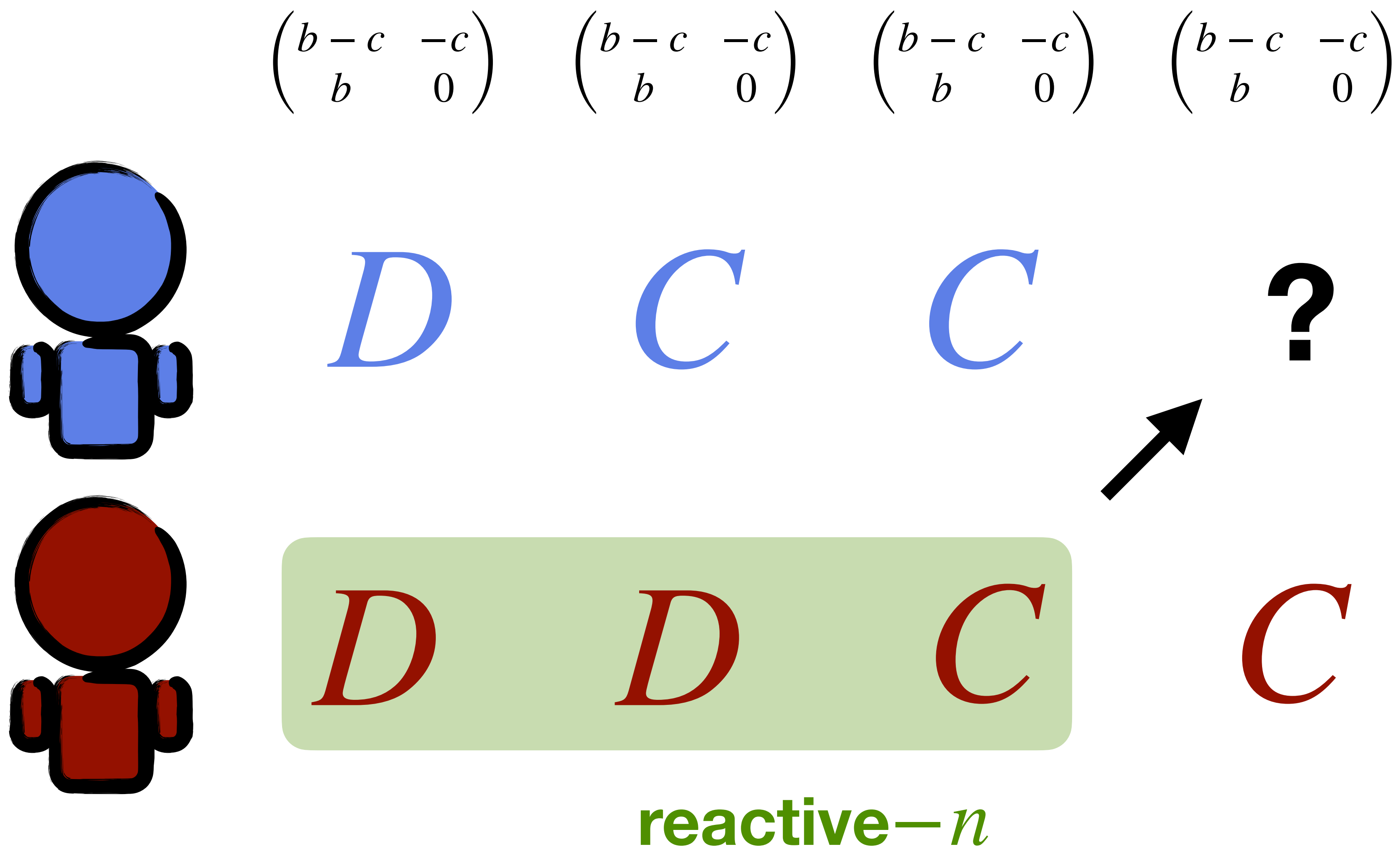

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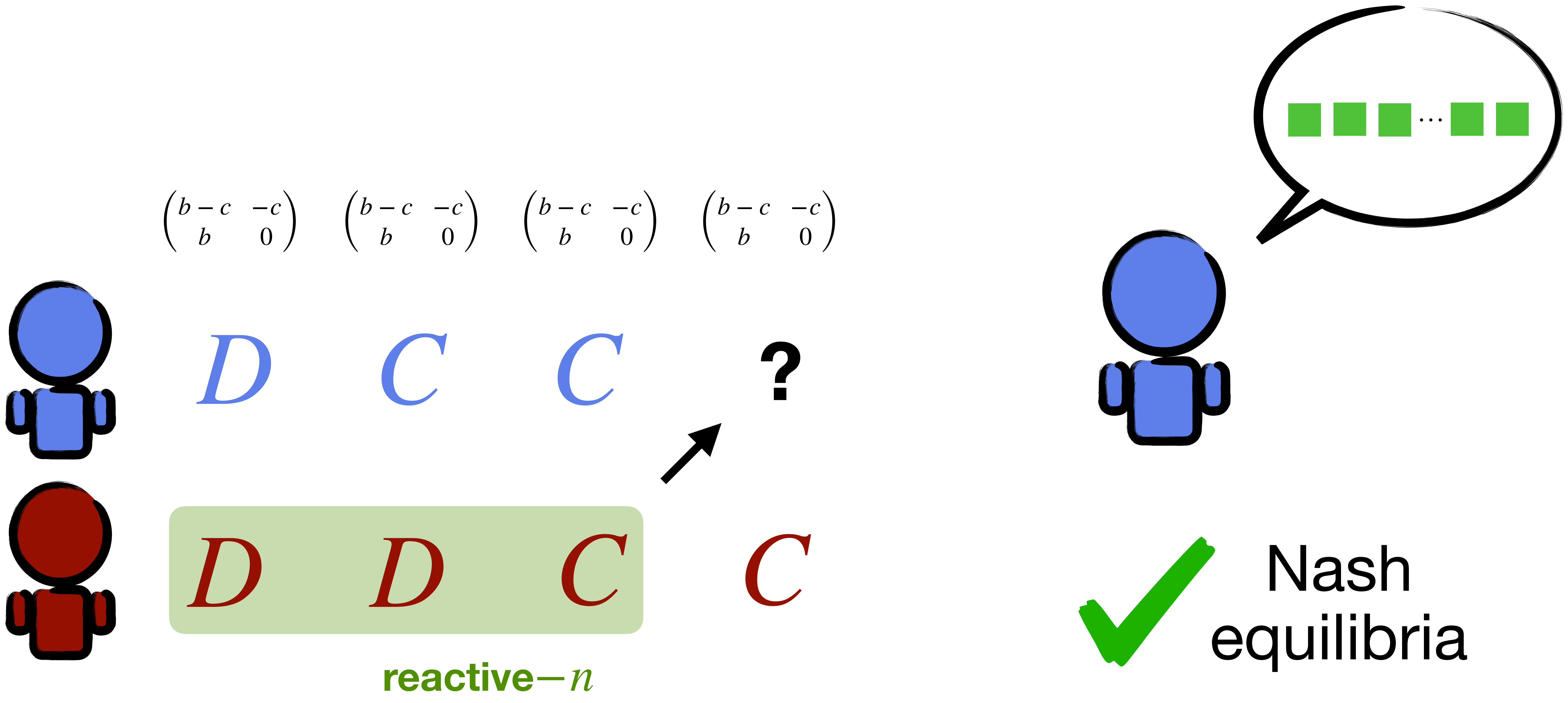

STRATEGIES IN REPEATED GAMES

STRATEGIES IN REPEATED GAMES

Definition 1.

A reactive-n strategy can be defined as 2^n-dimensional vector $\mathbf{p} = (p_{\mathbf{h^{-i}}})_{\mathbf{h^{-i}} \in H^{-i}}$ with $0 \leq p_{\mathbf{h^{-i}}} \leq 1$ where $\mathbf{h^{-i}}$ refers to an n-history of the co-player from the space of all possible co-player histories.

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Examples.

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Examples.

A reactive-1 strategy can be defined as: $\mathbf{p} = (p_C, p_D)$

STRATEGIES IN REPEATED GAMES

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A reactive-n strategy can be defined as 2^n-dimensional vector $\mathbf{p} = (p_{\mathbf{h^{-i}}})_{\mathbf{h^{-i}} \in H^{-i}}$ with $0 \leq p_{\mathbf{h^{-i}}} \leq 1$ where $\mathbf{h^{-i}}$ refers to an n-history of the co-player from the space of all possible co-player histories.

Examples.

A reactive-1 strategy can be defined as: $\mathbf{p} = (p_C, p_D)$

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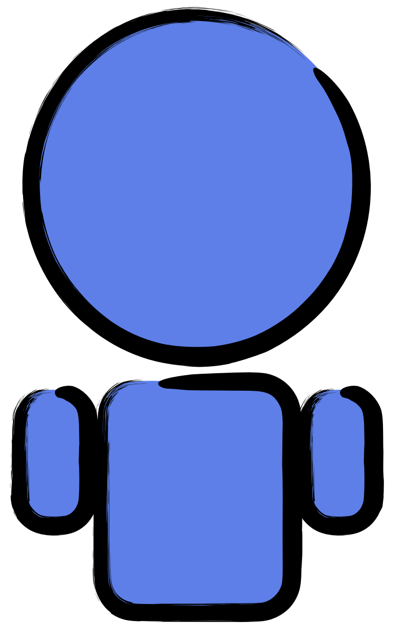
Definition 2.

A strategy $\mathbf{p}$ for a repeated game is a Nash equilibrium if it is a best response to itself.

That is $\pi(\mathbf{p}, \mathbf{p}) \geq \pi(\sigma, \mathbf{p})$ for all other strategies σ.



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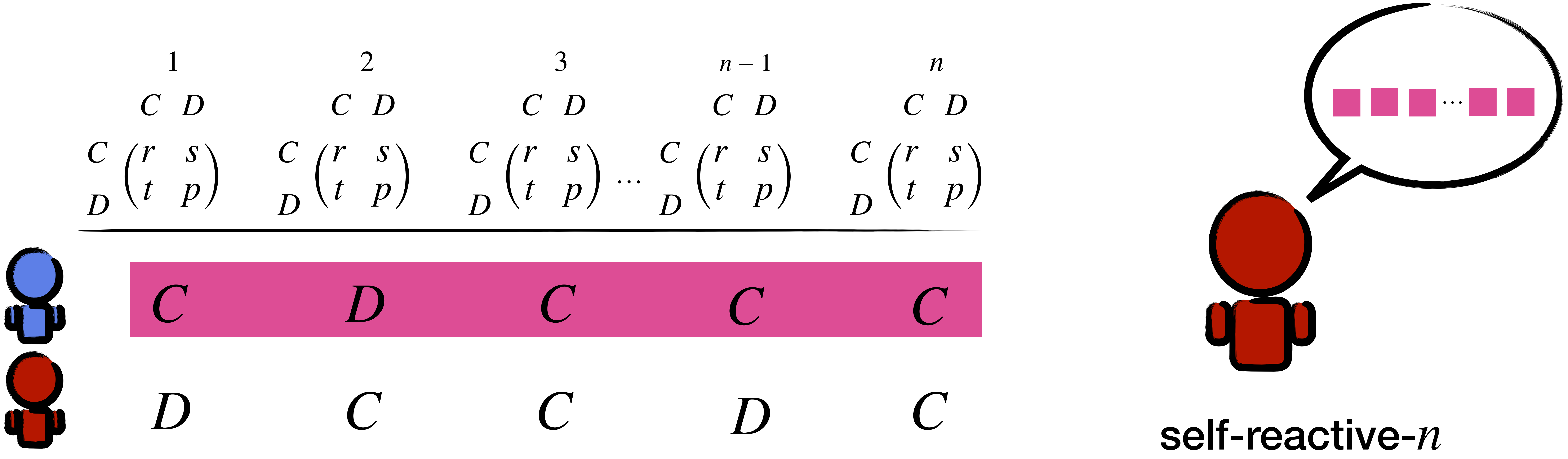

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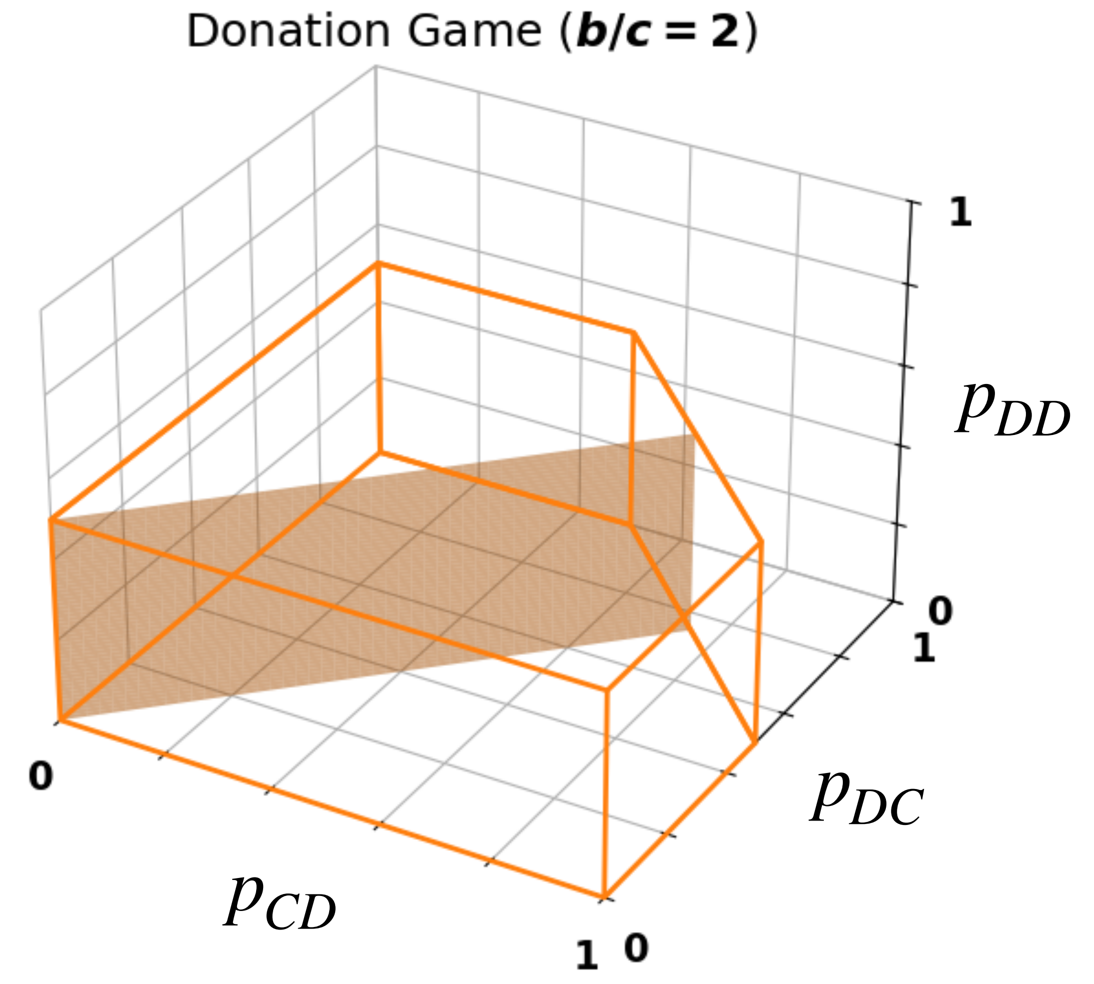

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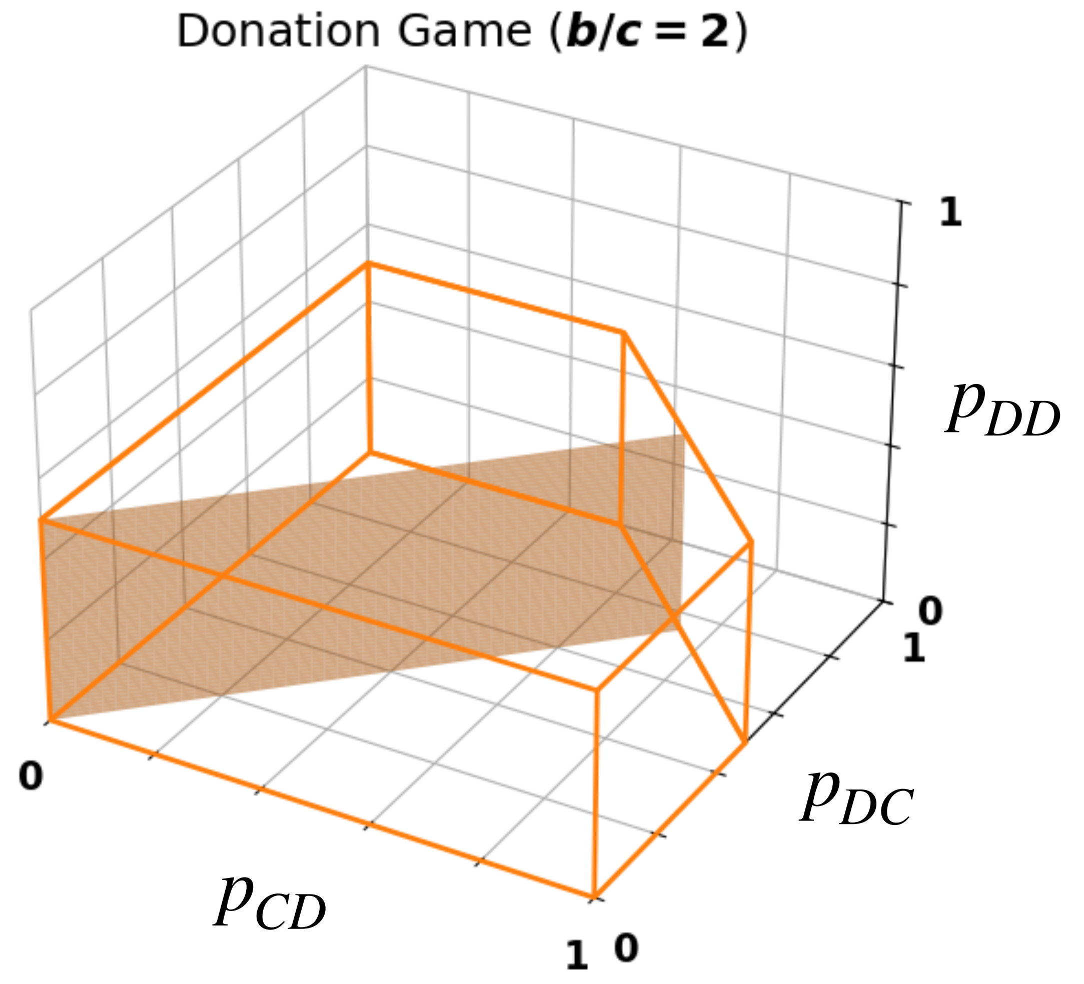

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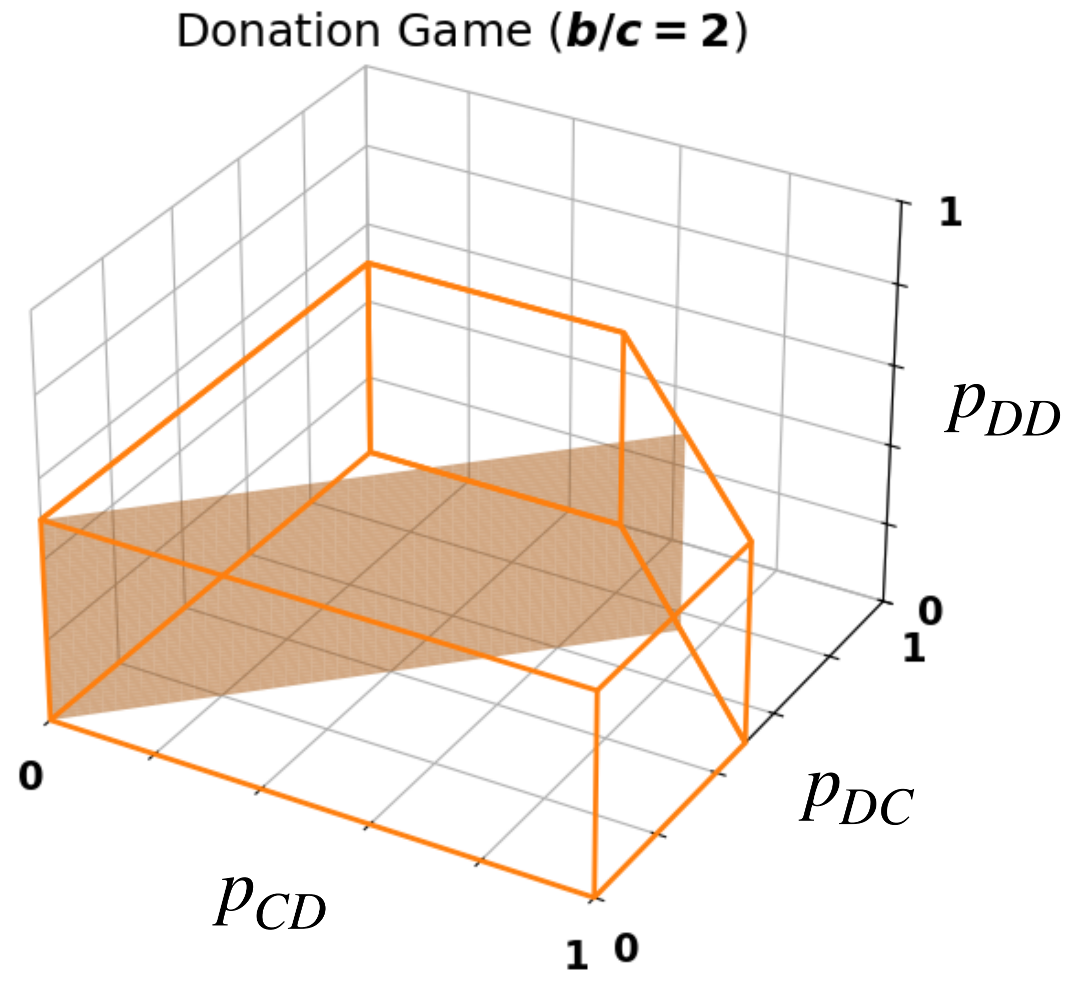

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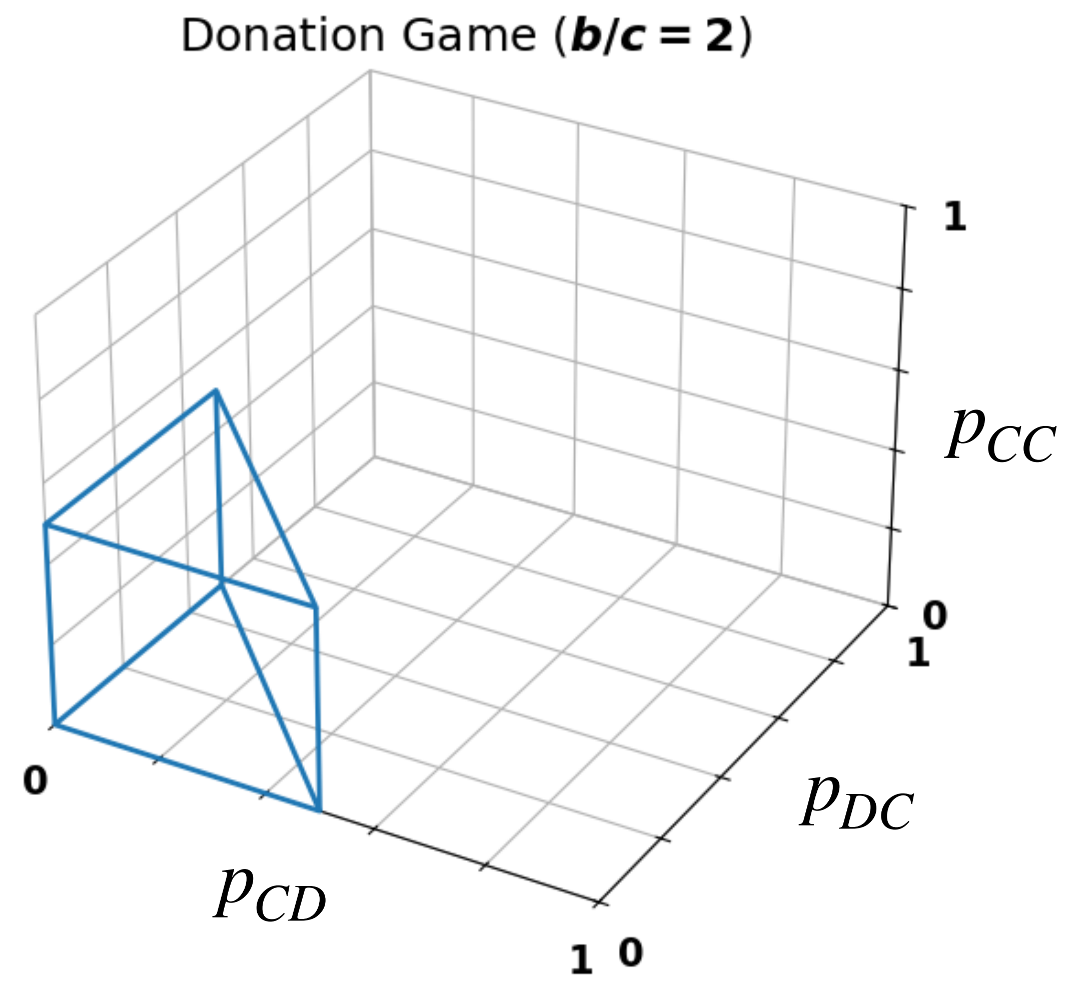

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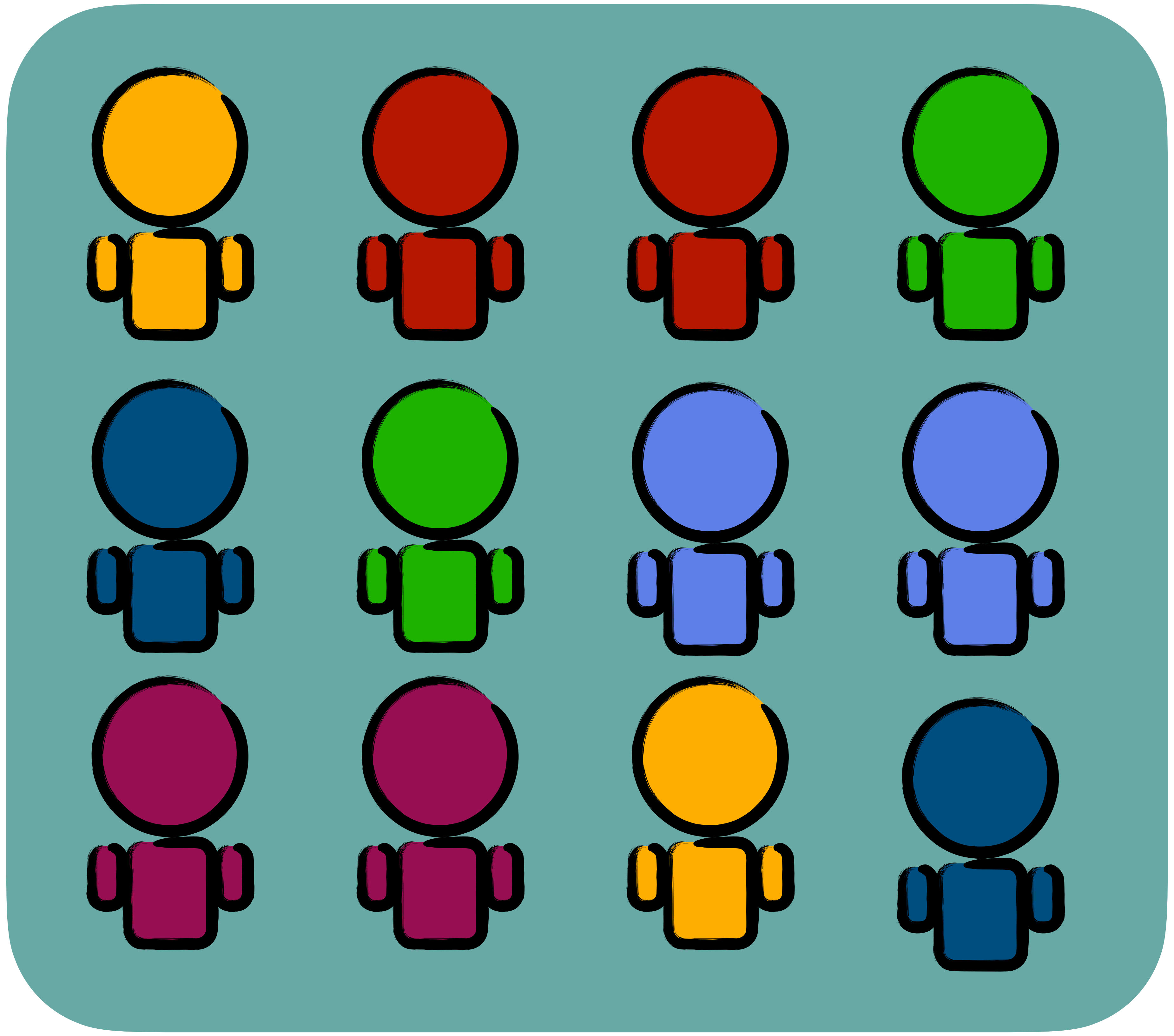

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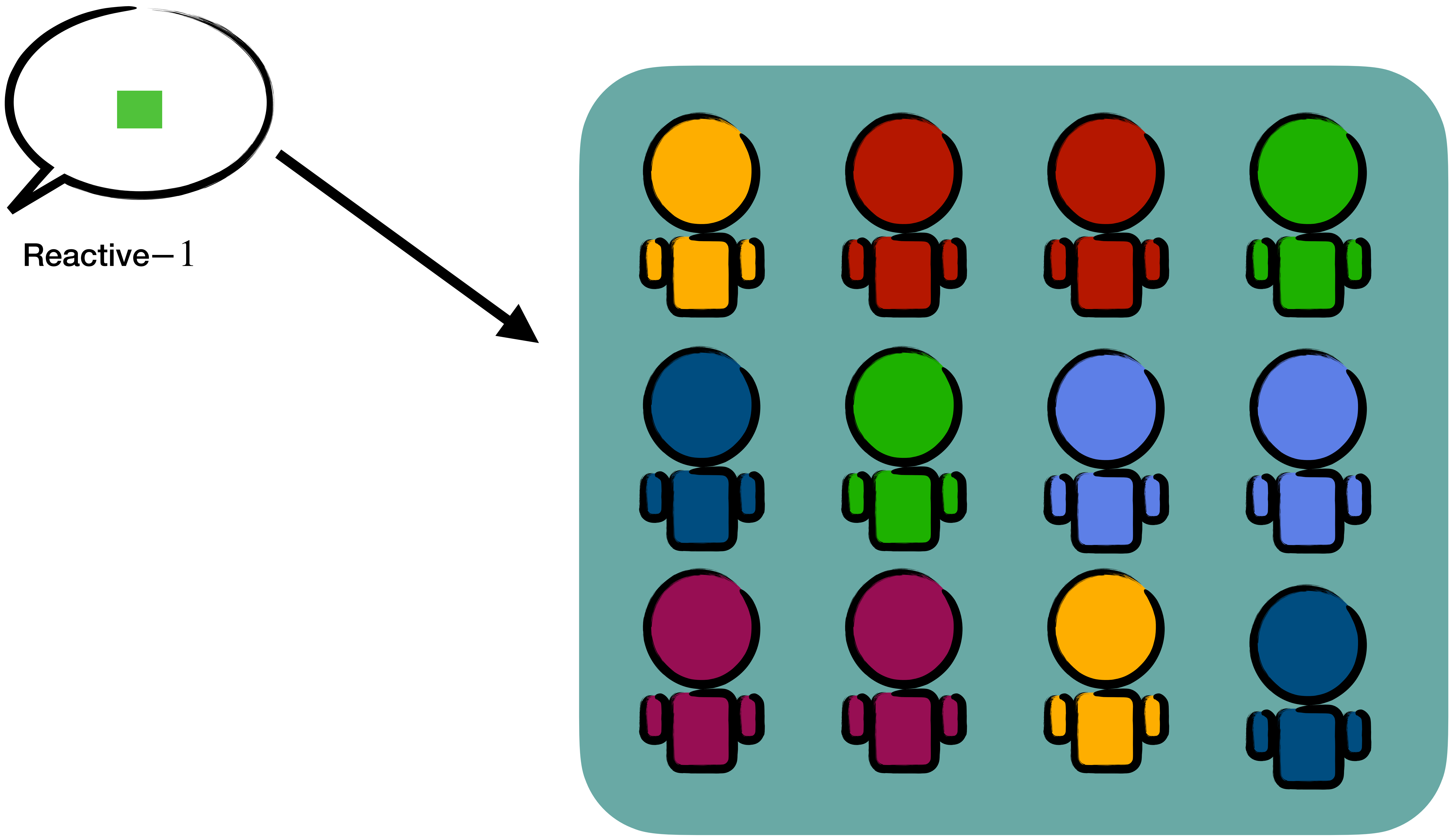

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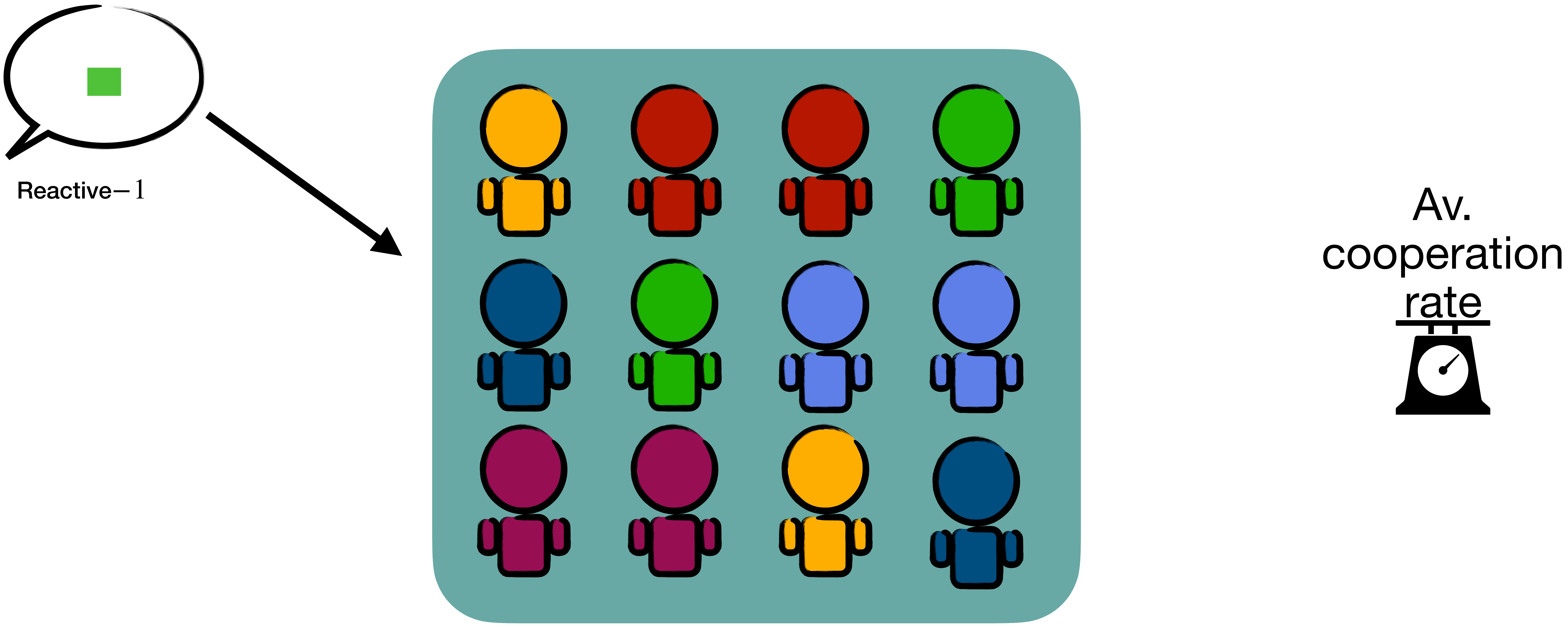

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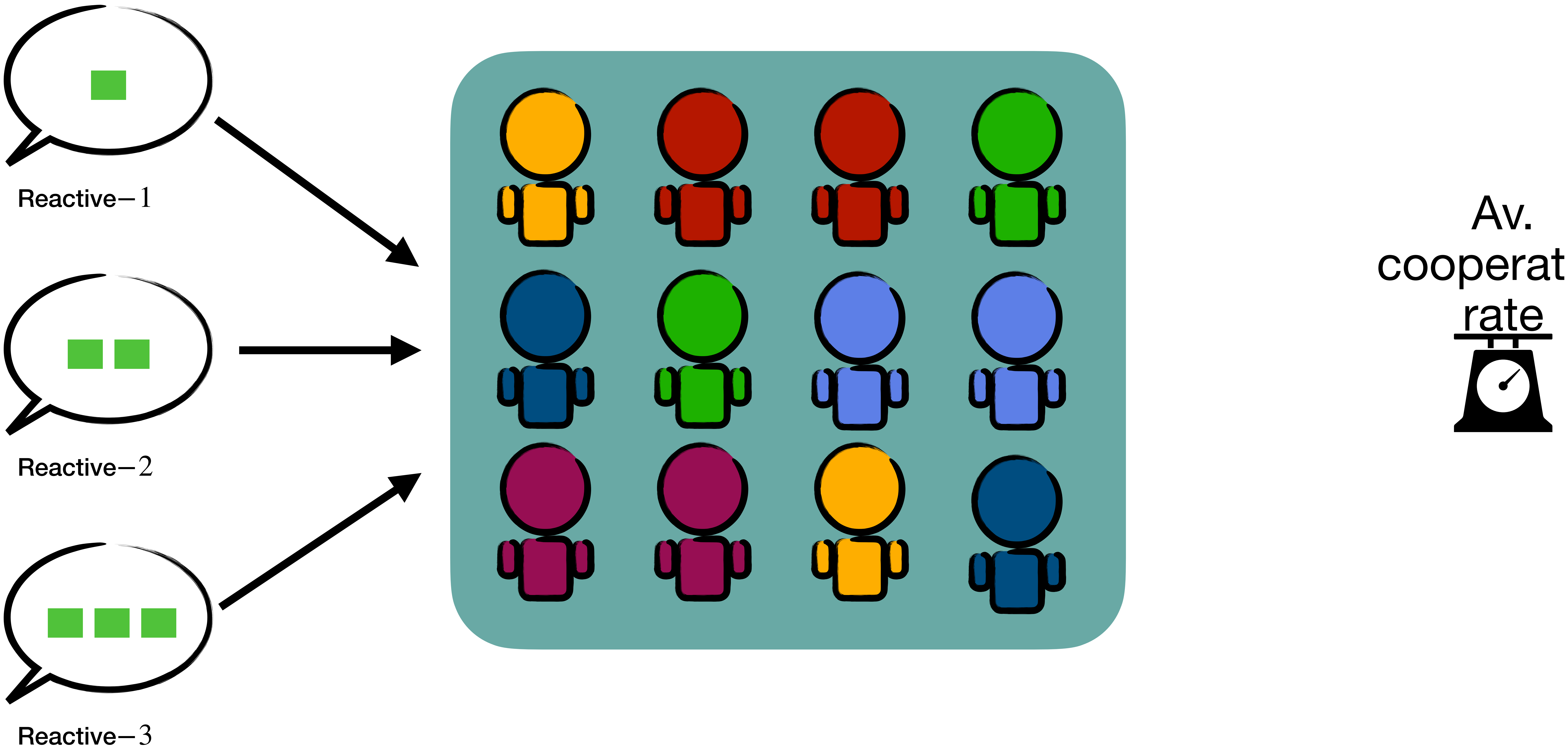

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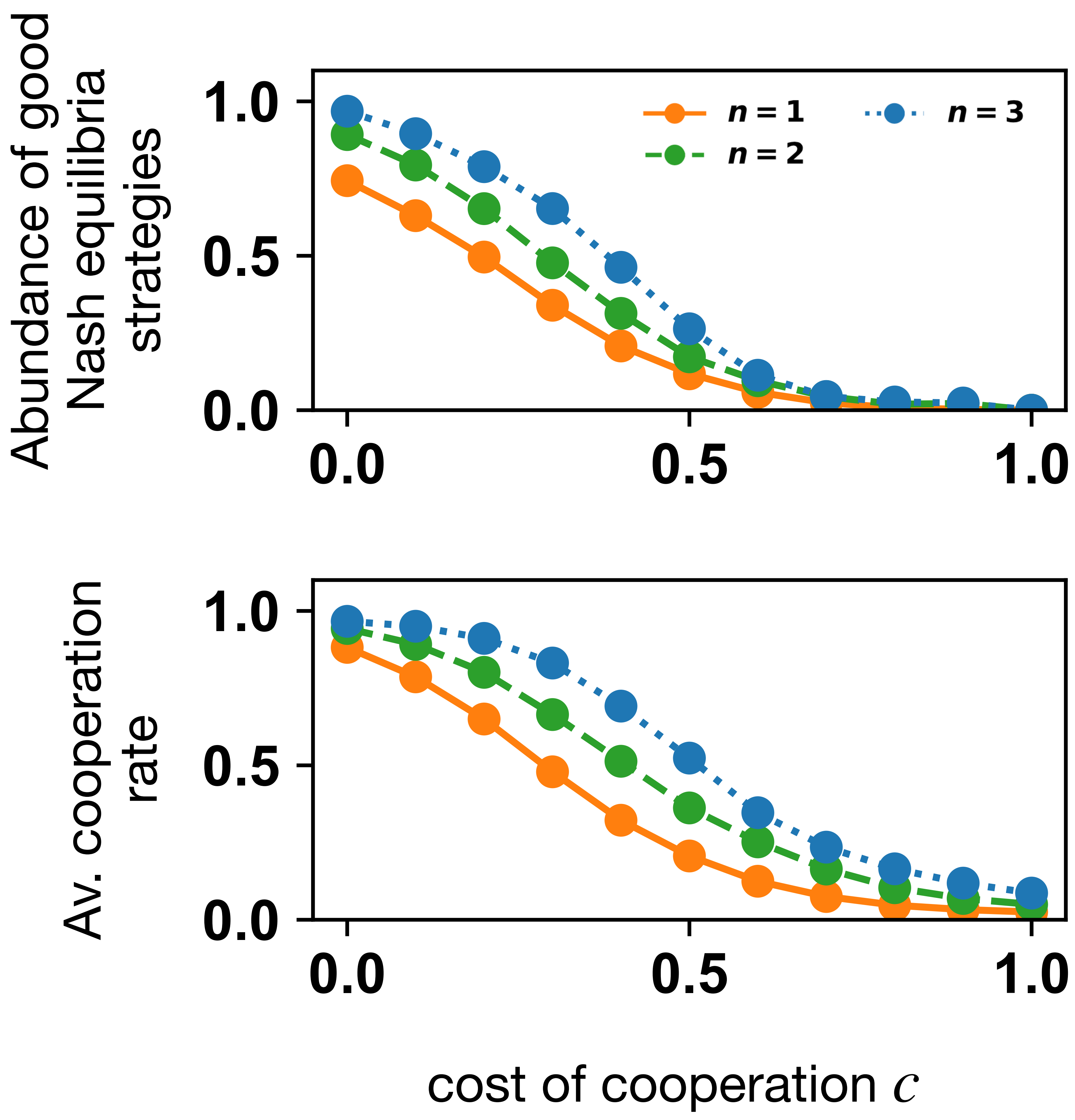

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[5] Conditional cooperation with longer memory. arXiv:2402.02437

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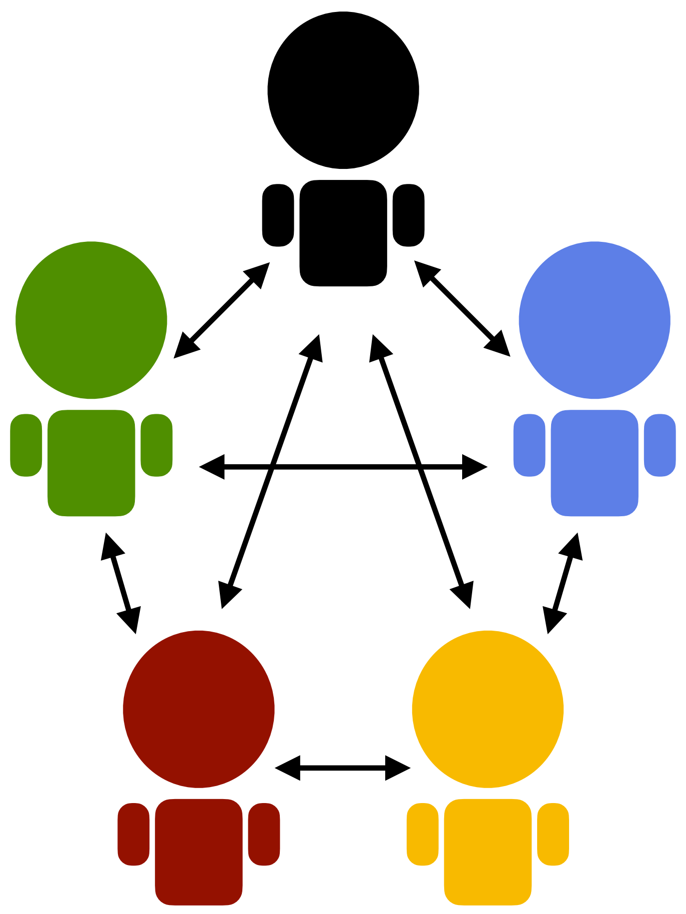

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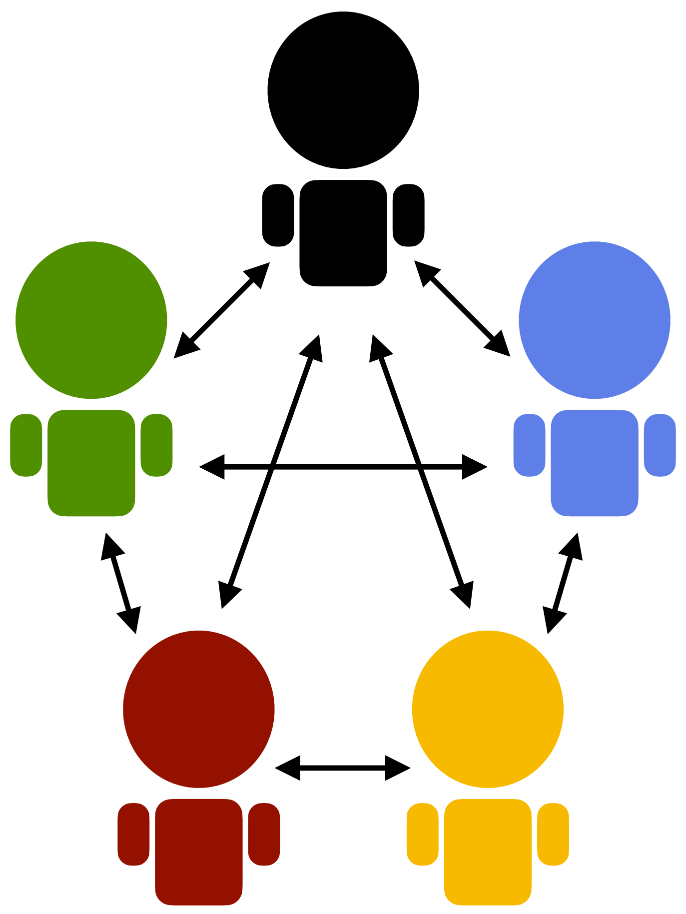

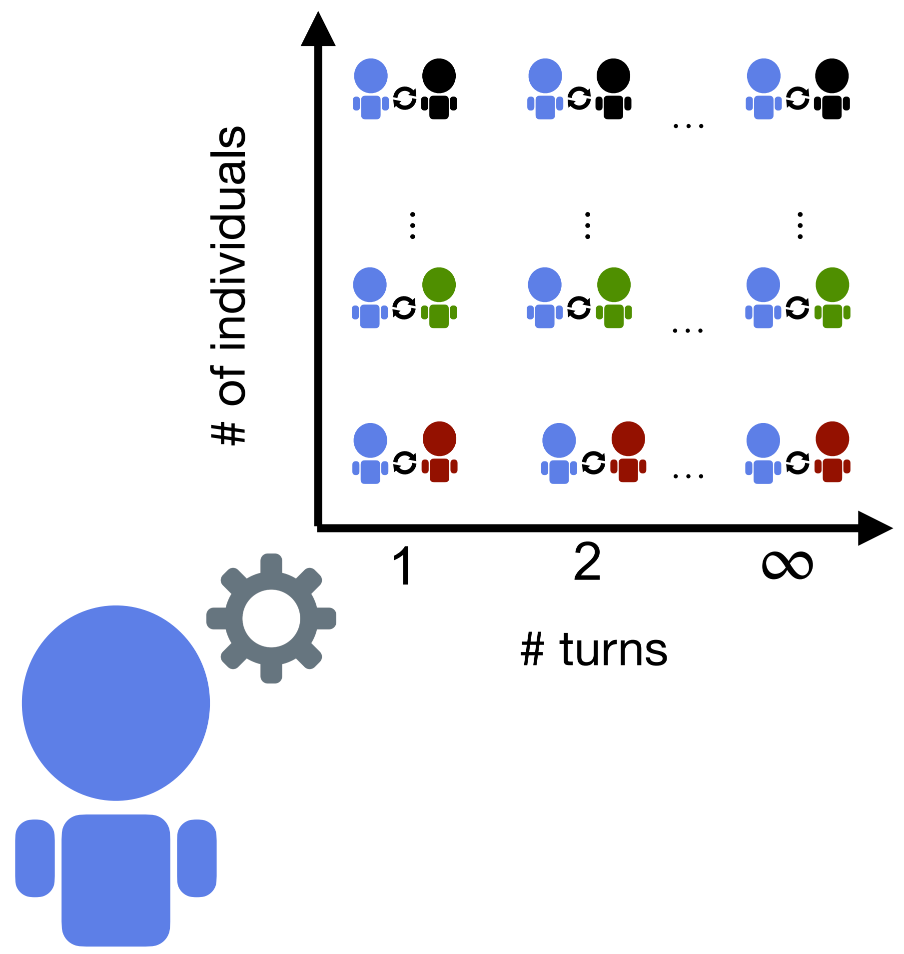

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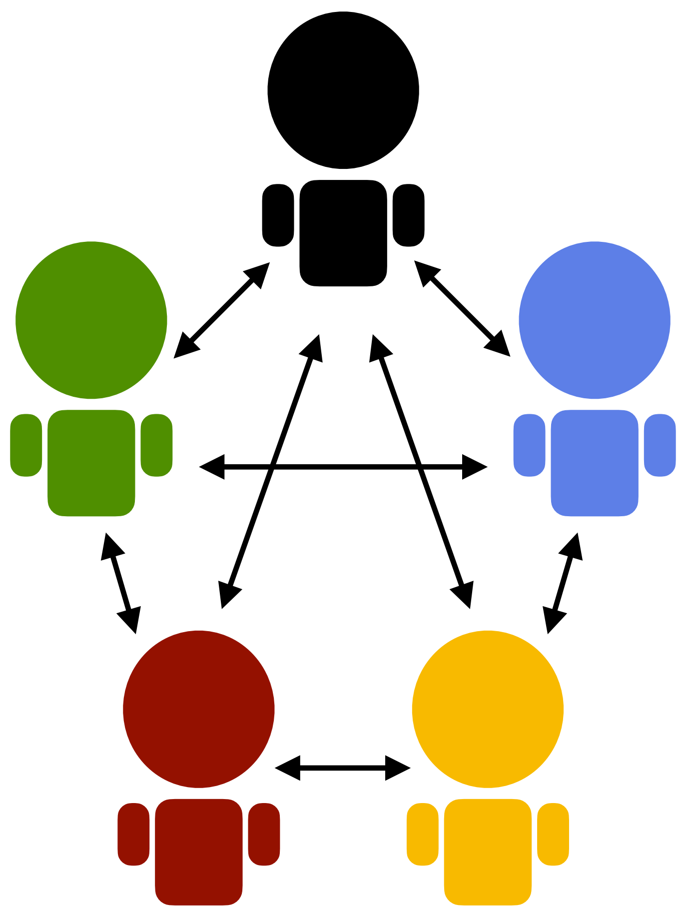

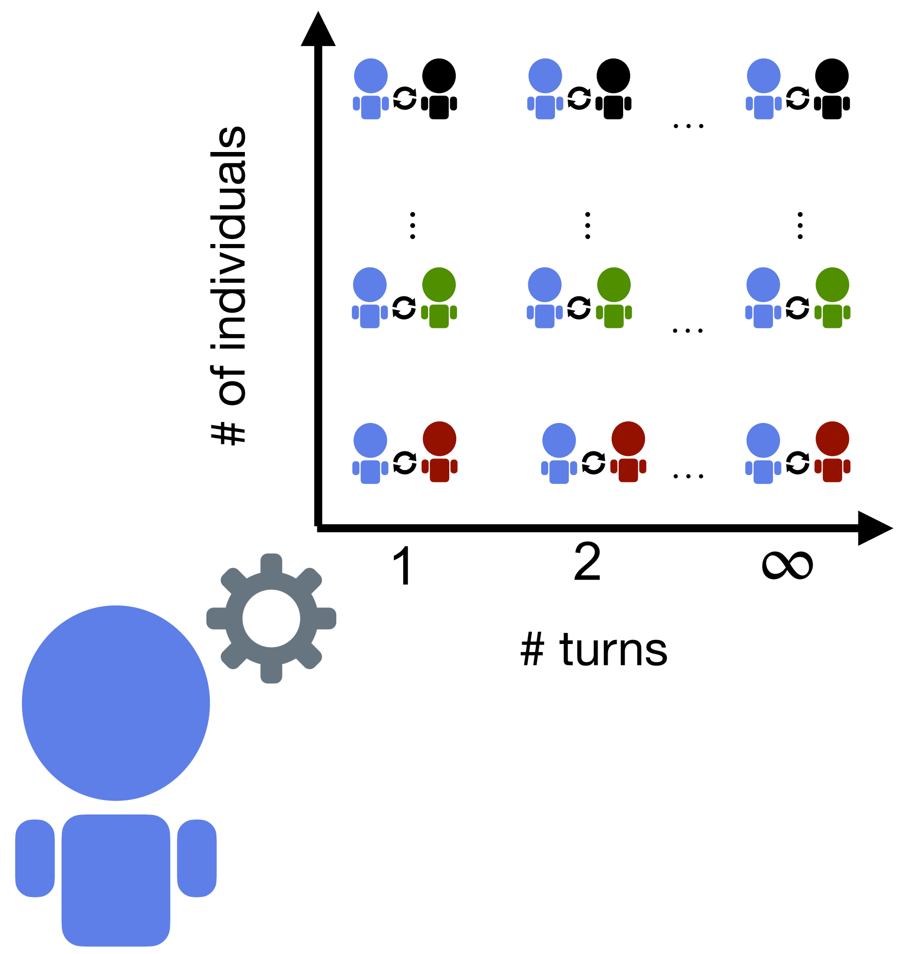

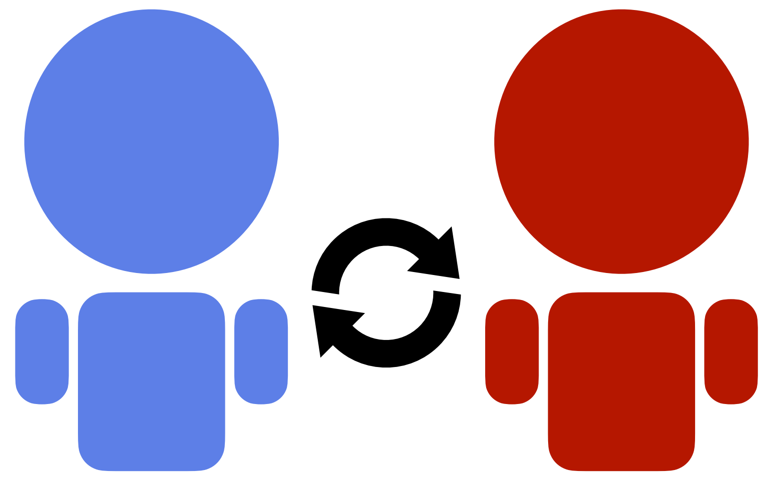

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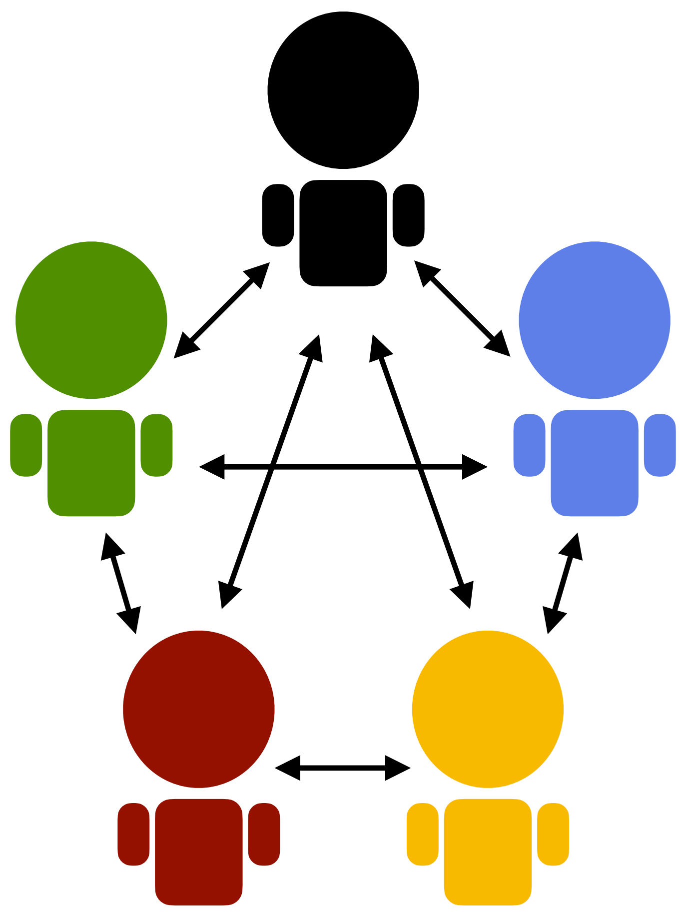

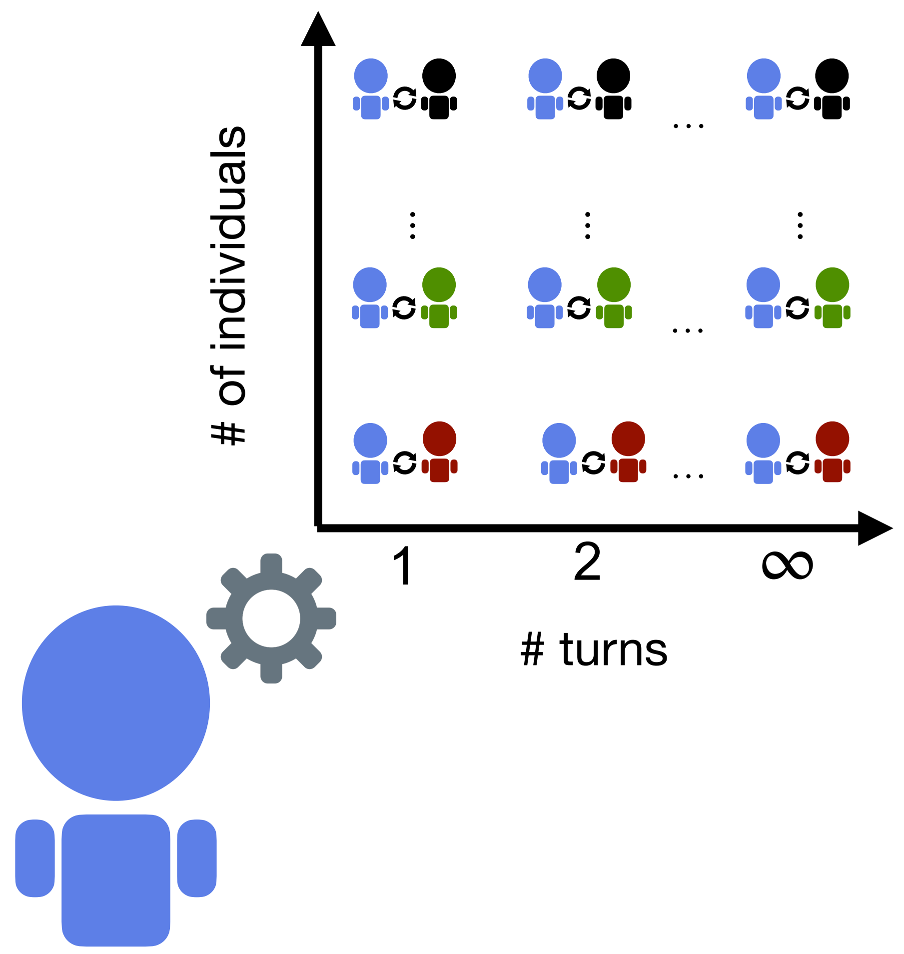

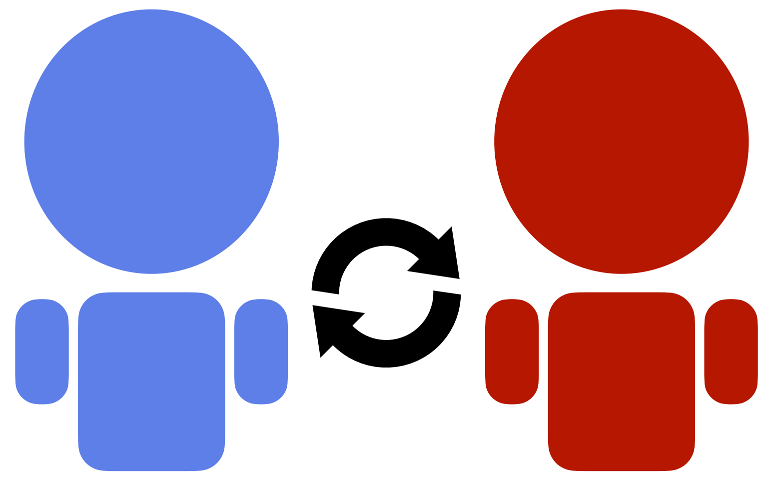

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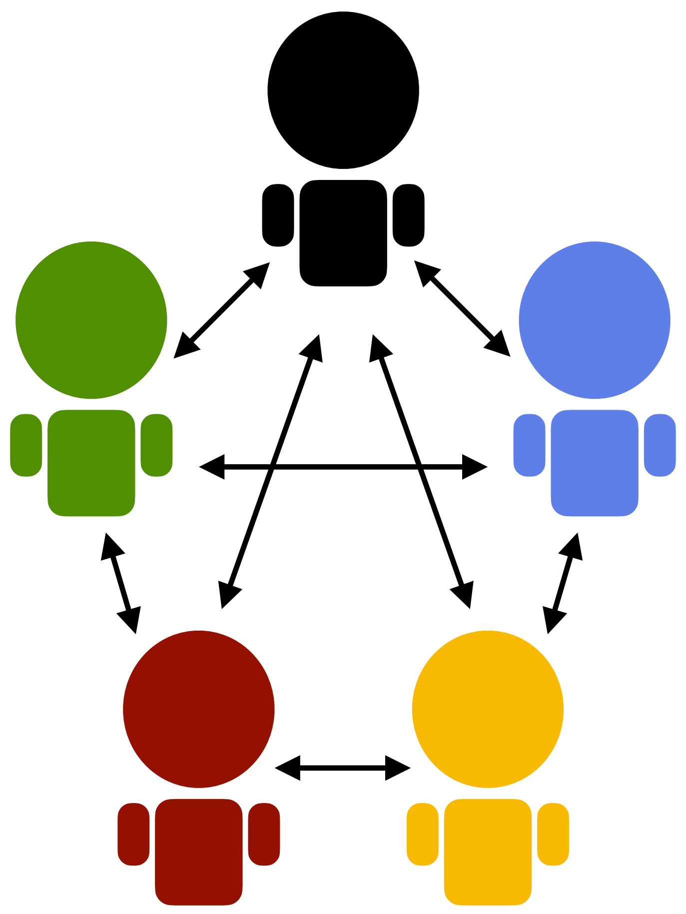
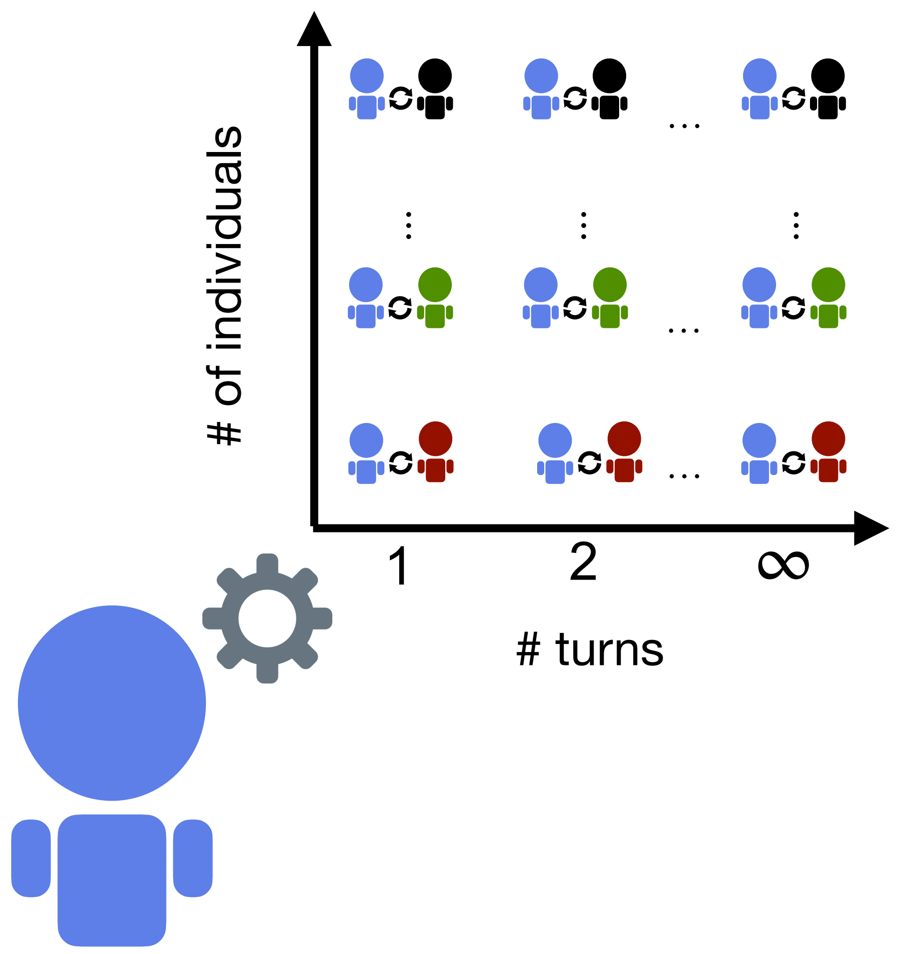
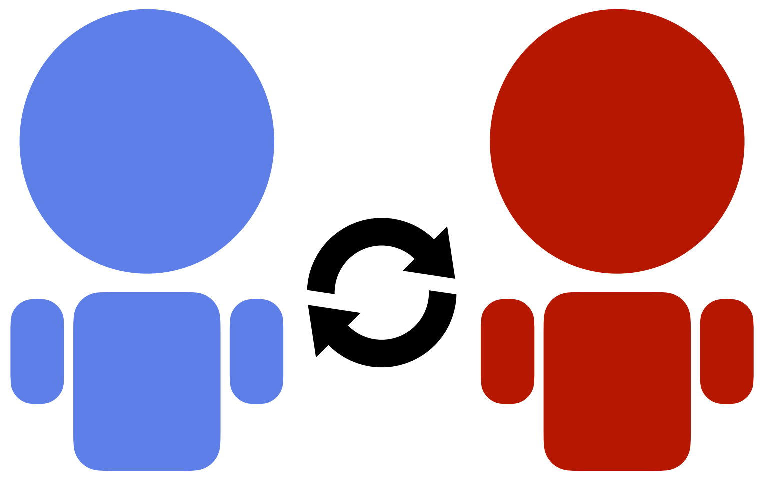
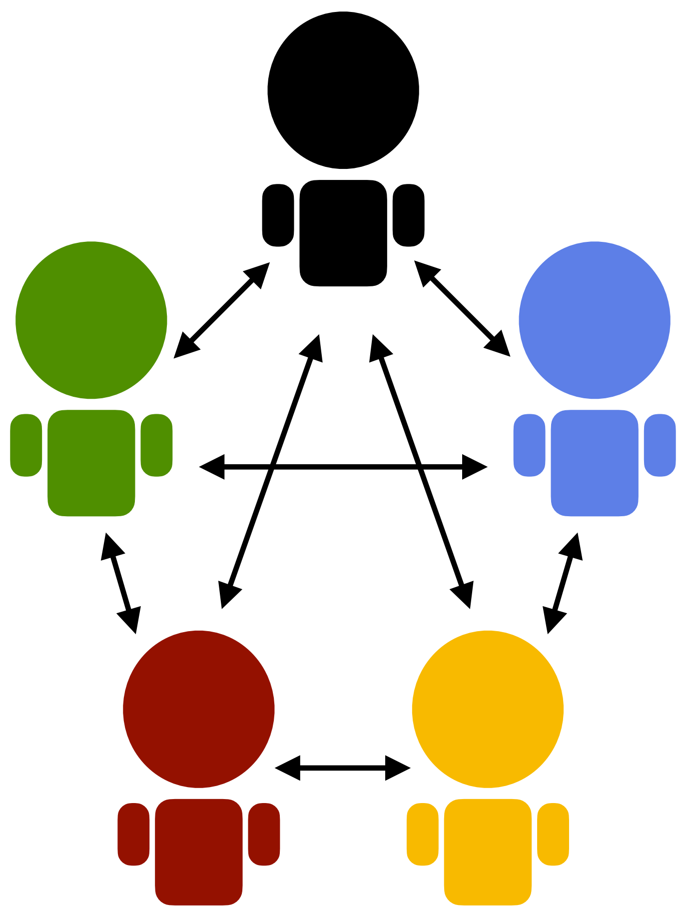
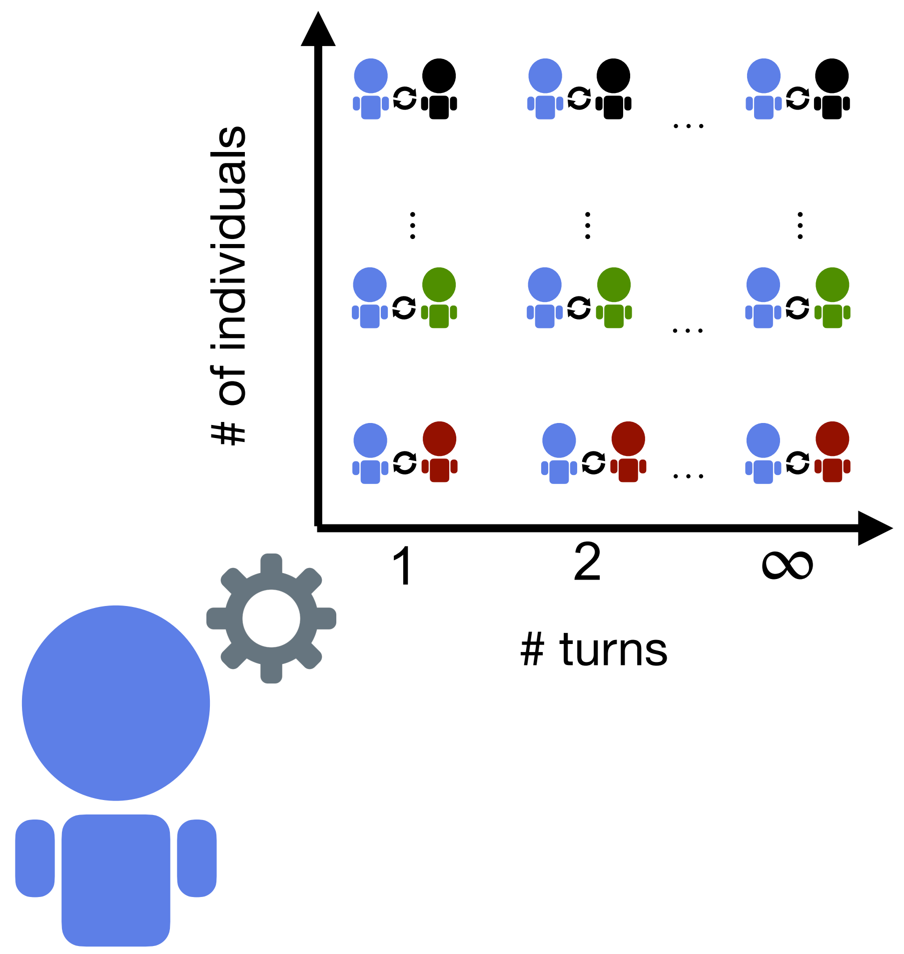


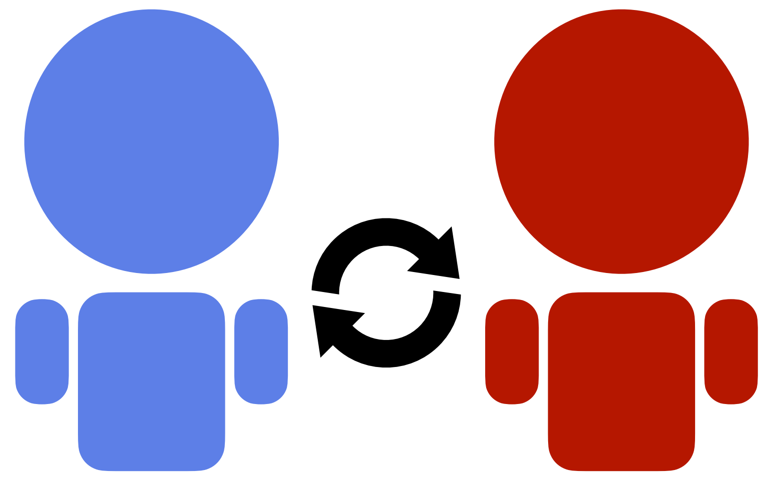


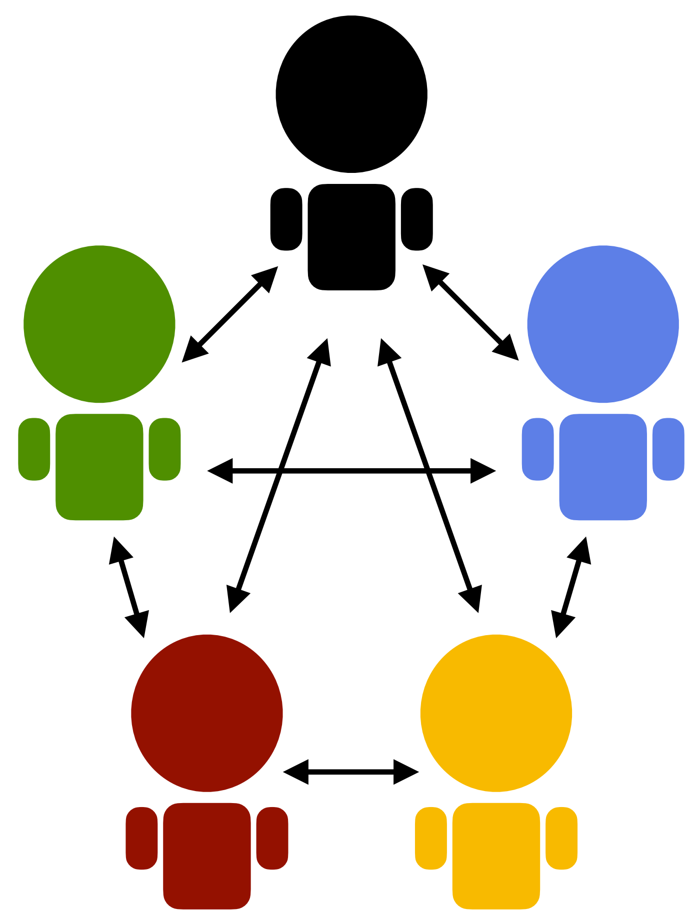


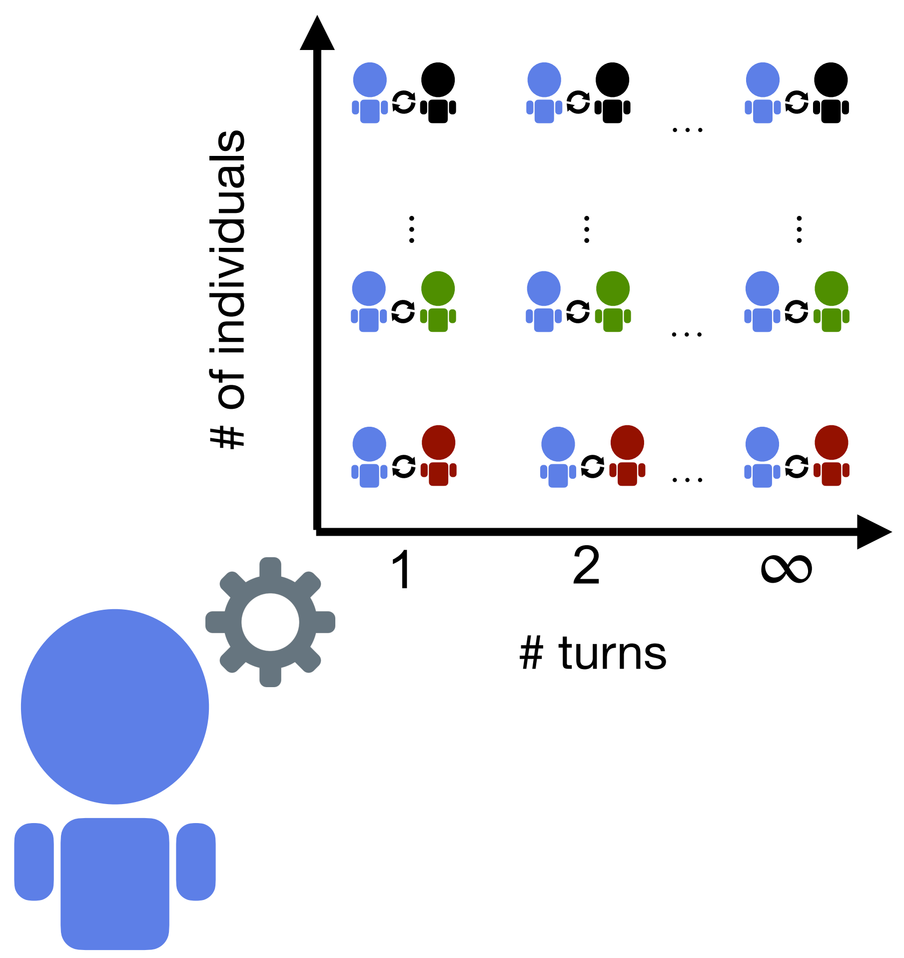




# of individuals
1
2
∞
turns



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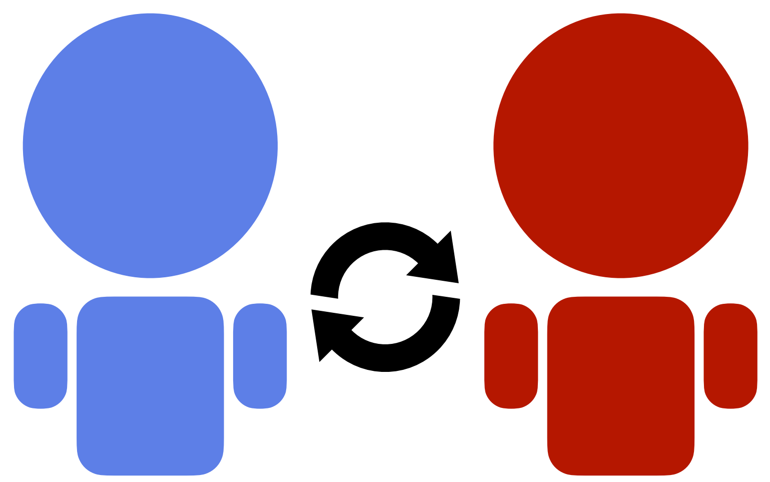

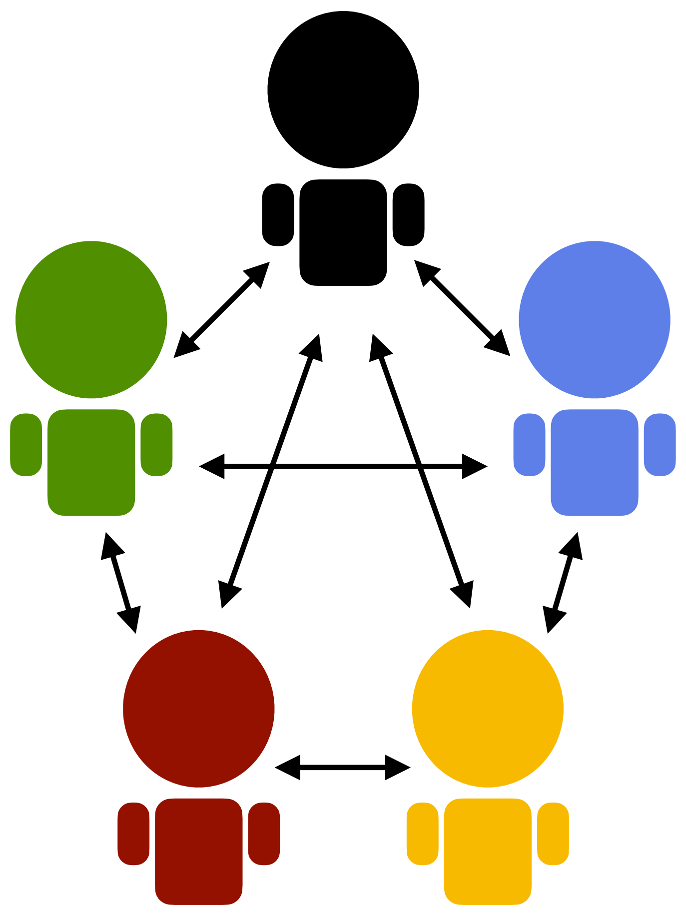

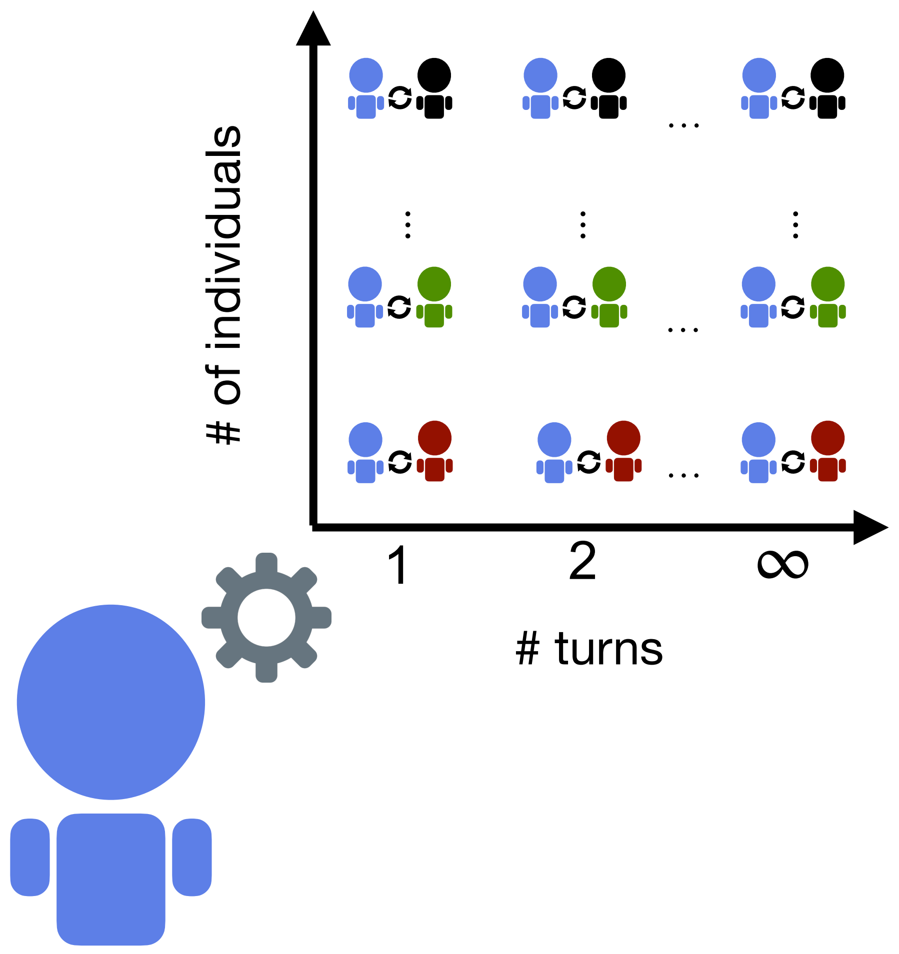

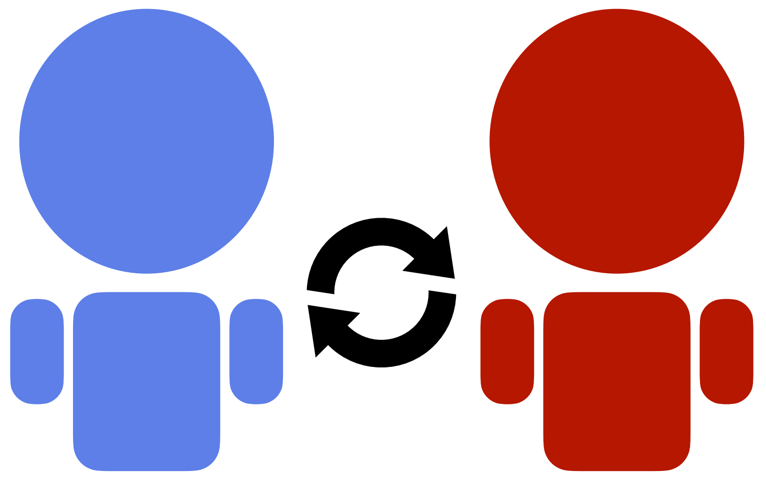

Publications

[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.
https://doi.org/10.1098/rspb.2023.2493

[5] Conditional cooperation with longer memory. arXiv:2402.02437

Collaborators

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Nikoleta-v3

@NikoletaGlyn

http://nikoleta-v3.github.io

THANK YOU!