An overview

Two days ago's class (March 11, 2025)

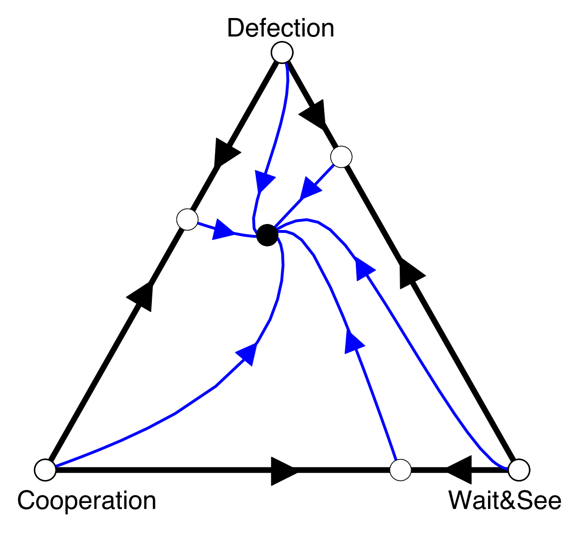
- An introduction to evolutionary game theory
  (Replicator dynamics, games in finite populations)

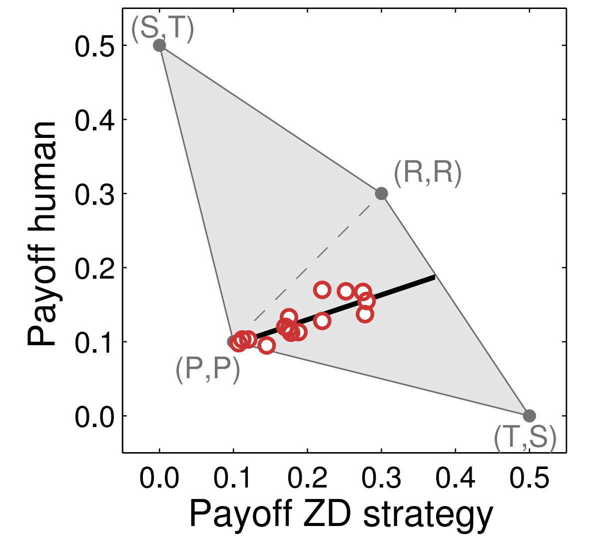
Yesterday's class (March 12, 2025)

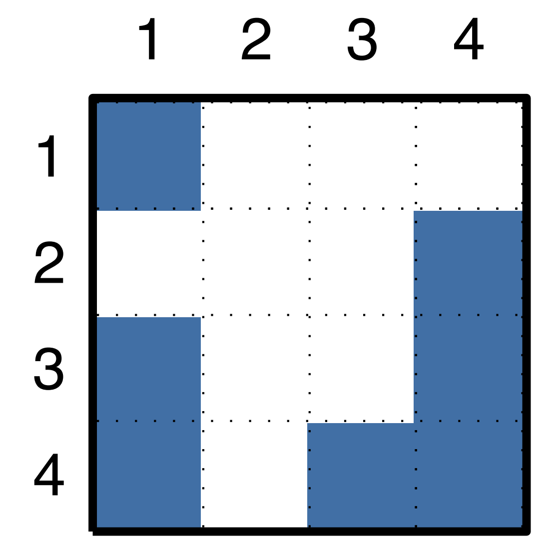
- Evolution of cooperation & direct reciprocity
- Social norms & indirect reciprocity

Today's class (March 13, 2025)

- Some current research: Reciprocity in complex environments







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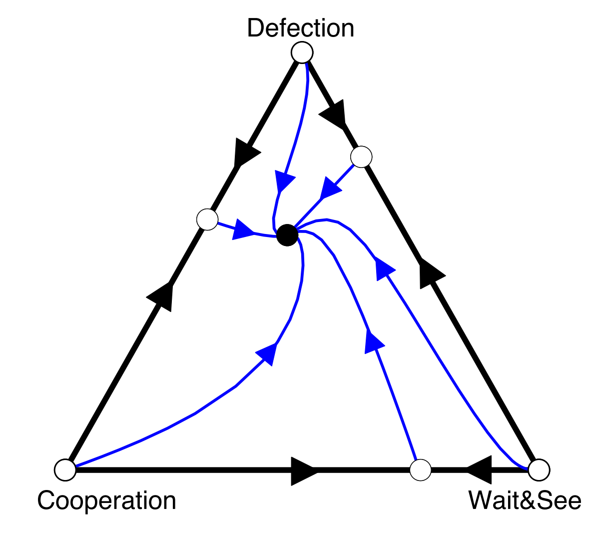
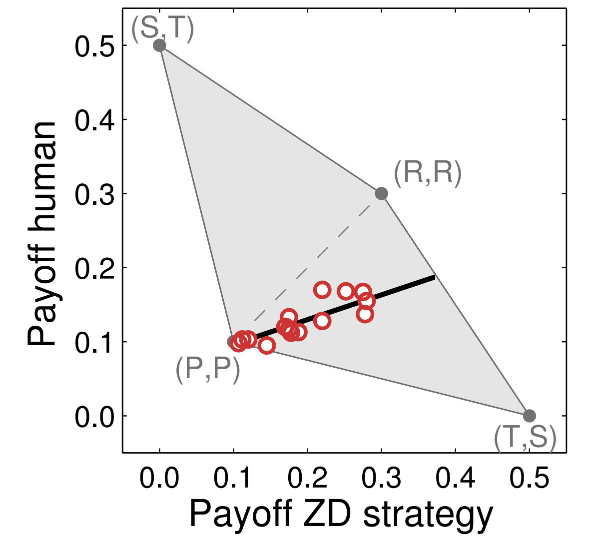
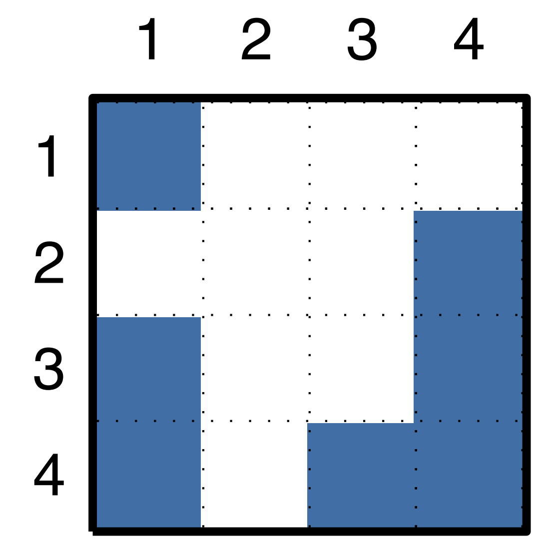
The role of memory; the effect of changing environments; the impact of inequality







The impact of memory: Results on memory-1

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Iterated Prisoner's Dilemma contains strategies that dominate any evolutionary opponent

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Corollary 4.3. Checking for Nash

If **p** is a memory-1 strategy, then (**p**,**p**) is a Nash equilibrium if and only if there is no profitable deviation towards another memory-1 strategy.

The impact of memory: More is different

Theorem 4.4. Checking for Nash, part II [Akin 2015]

Suppose **p** is a *nice* memory-1 strategy (it is never the first to defect, $p_0 = p_{CC} = 1$. Then(**p**,**p**) is a Nash equilibrium if and only if neither a deviation towards ALLD, nor a deviation to **q**=(0,0,1,1,1) is profitable.

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  Transition matrix for memory-1: 4x4
  Transition matrix for memory-2: 16x16
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The impact of memory: Reactive-n strategies

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A memory-n strategy **q** is called reactive, if it only depends *on the co-player's* last n decisions.

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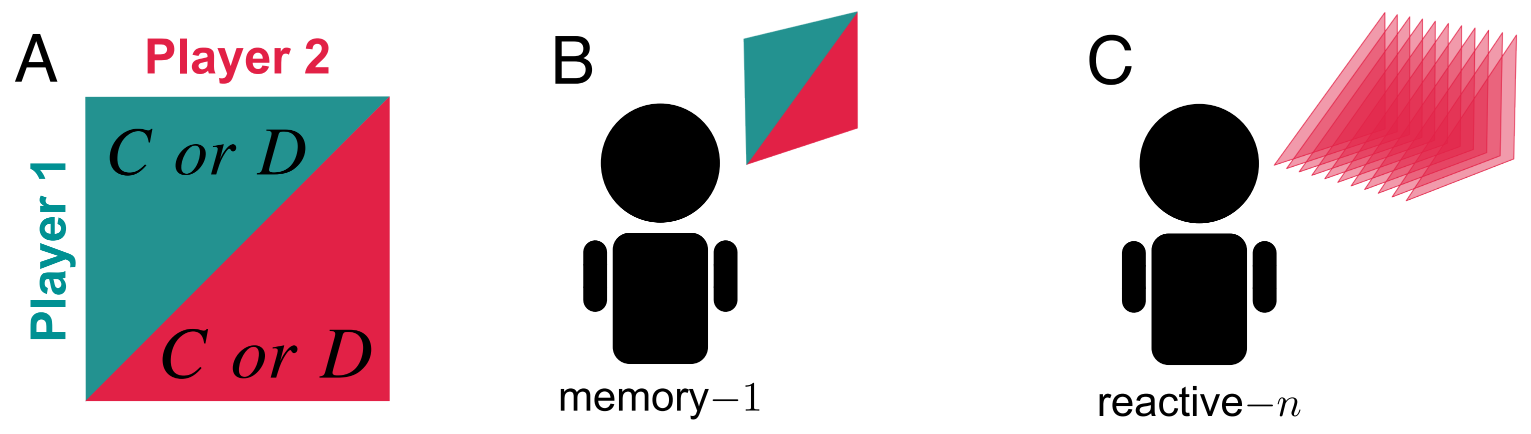

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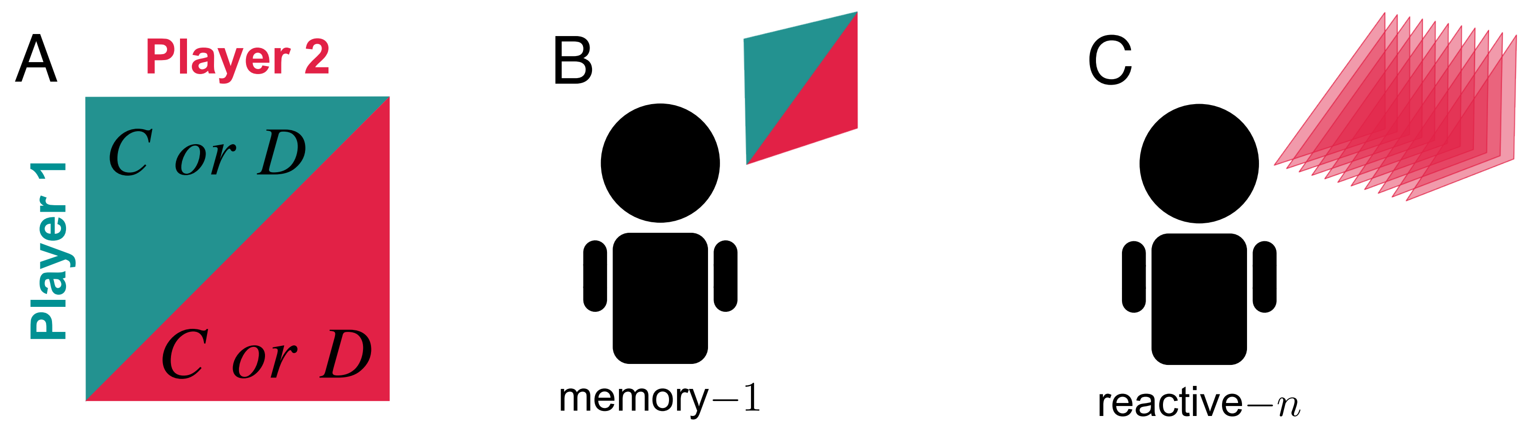

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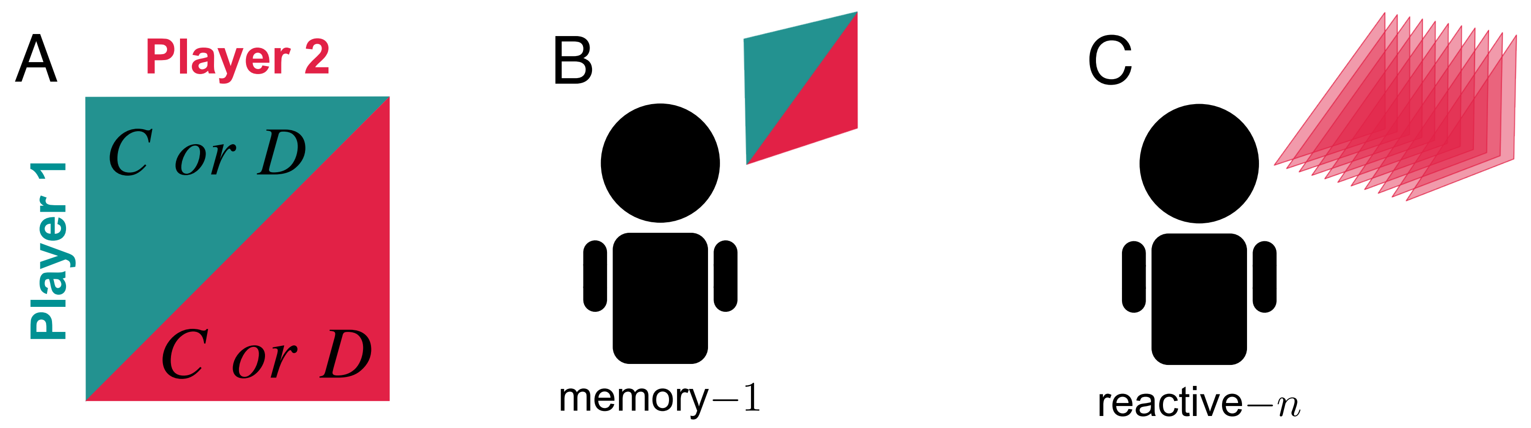

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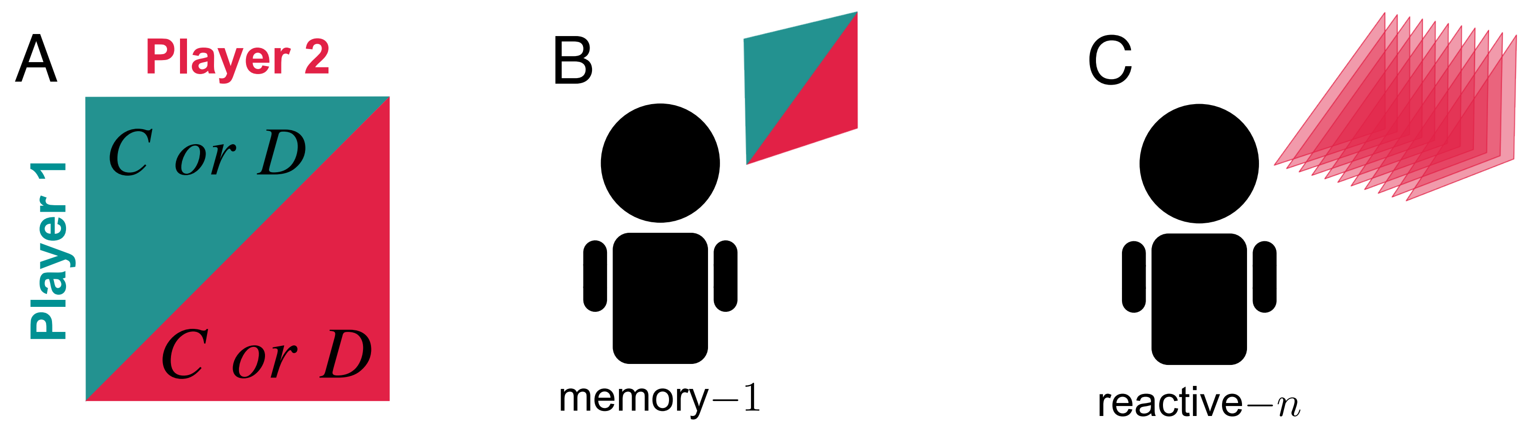

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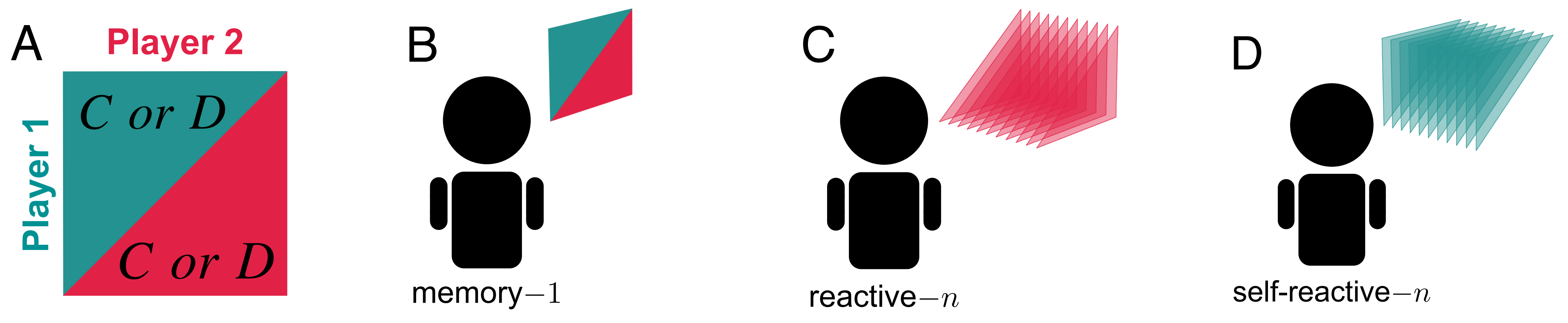

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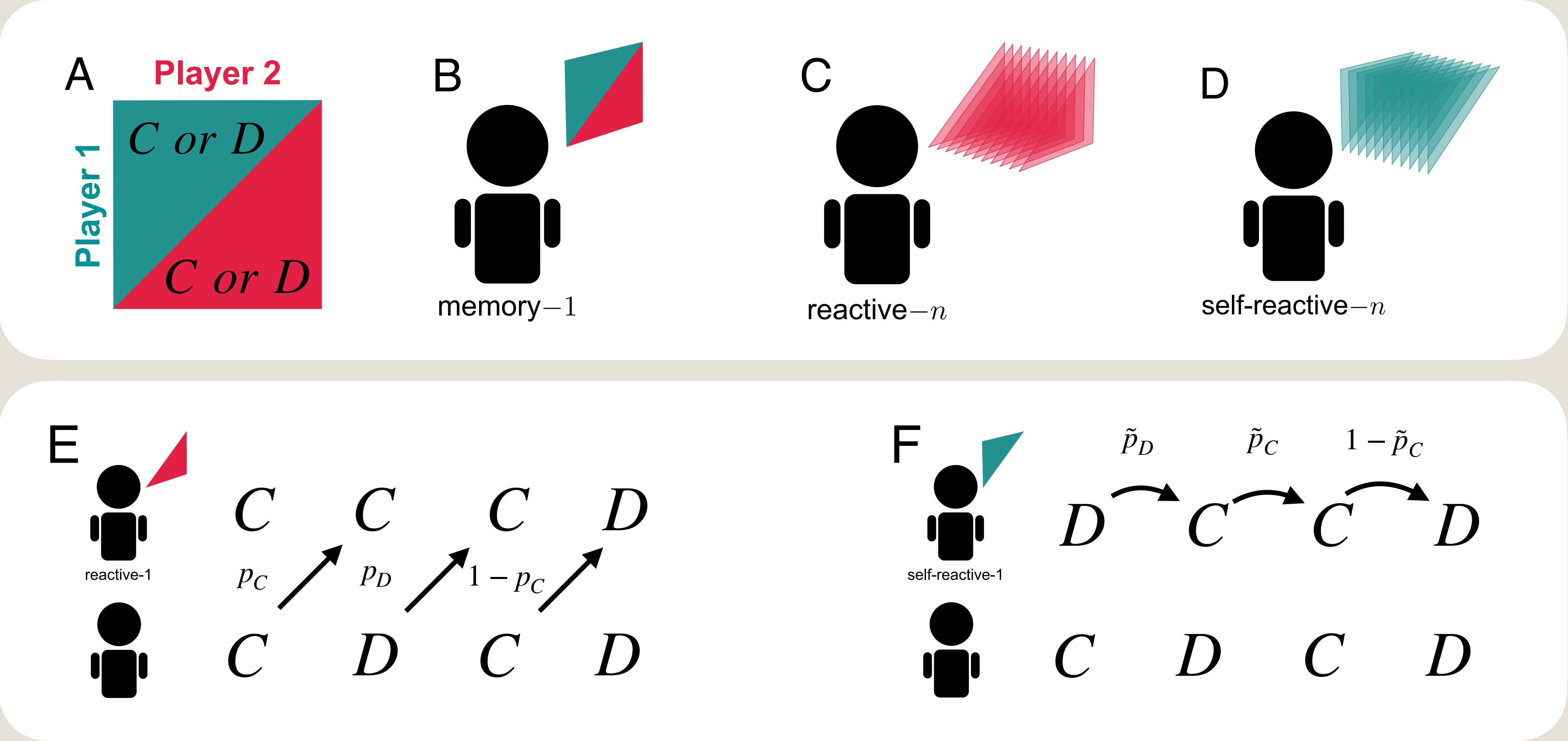

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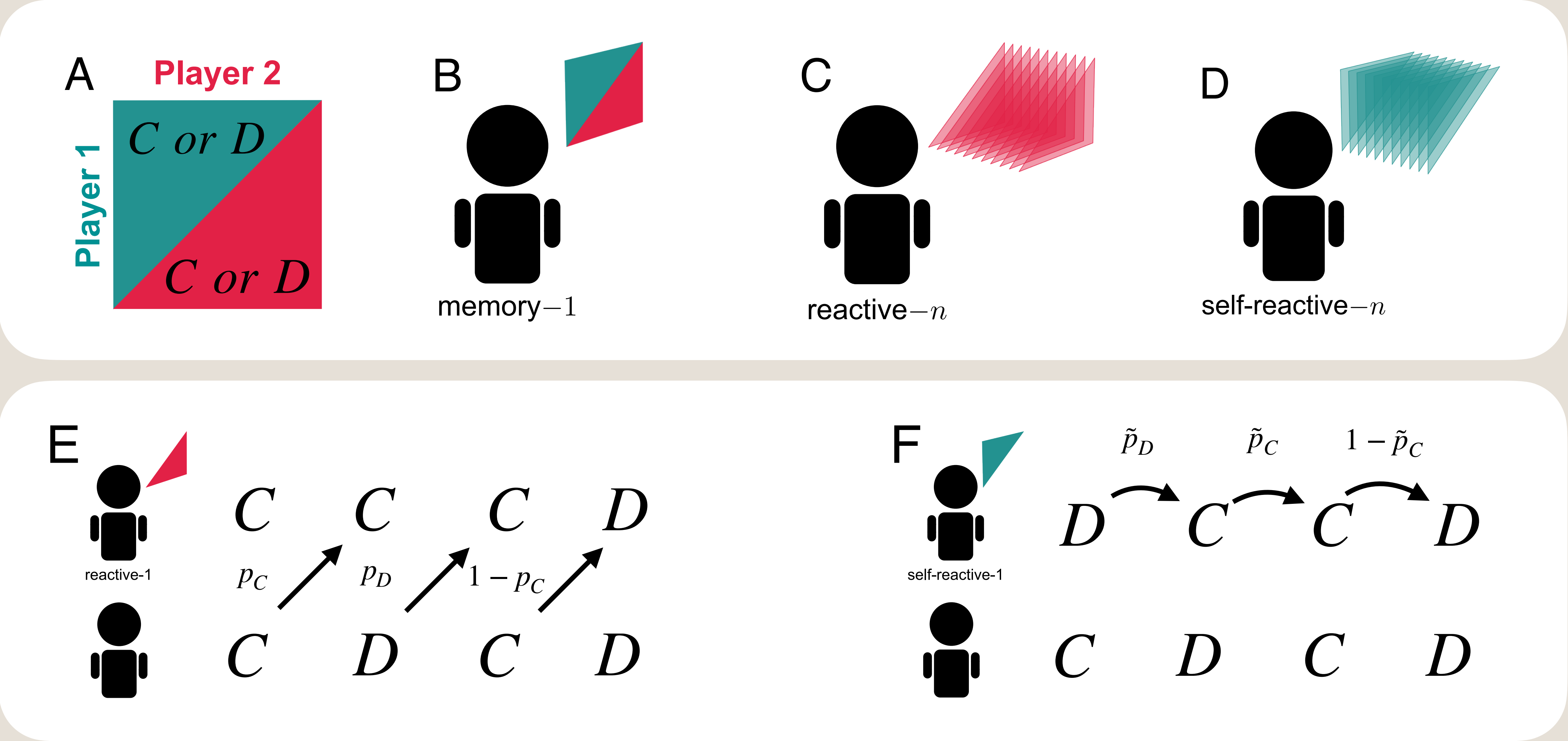

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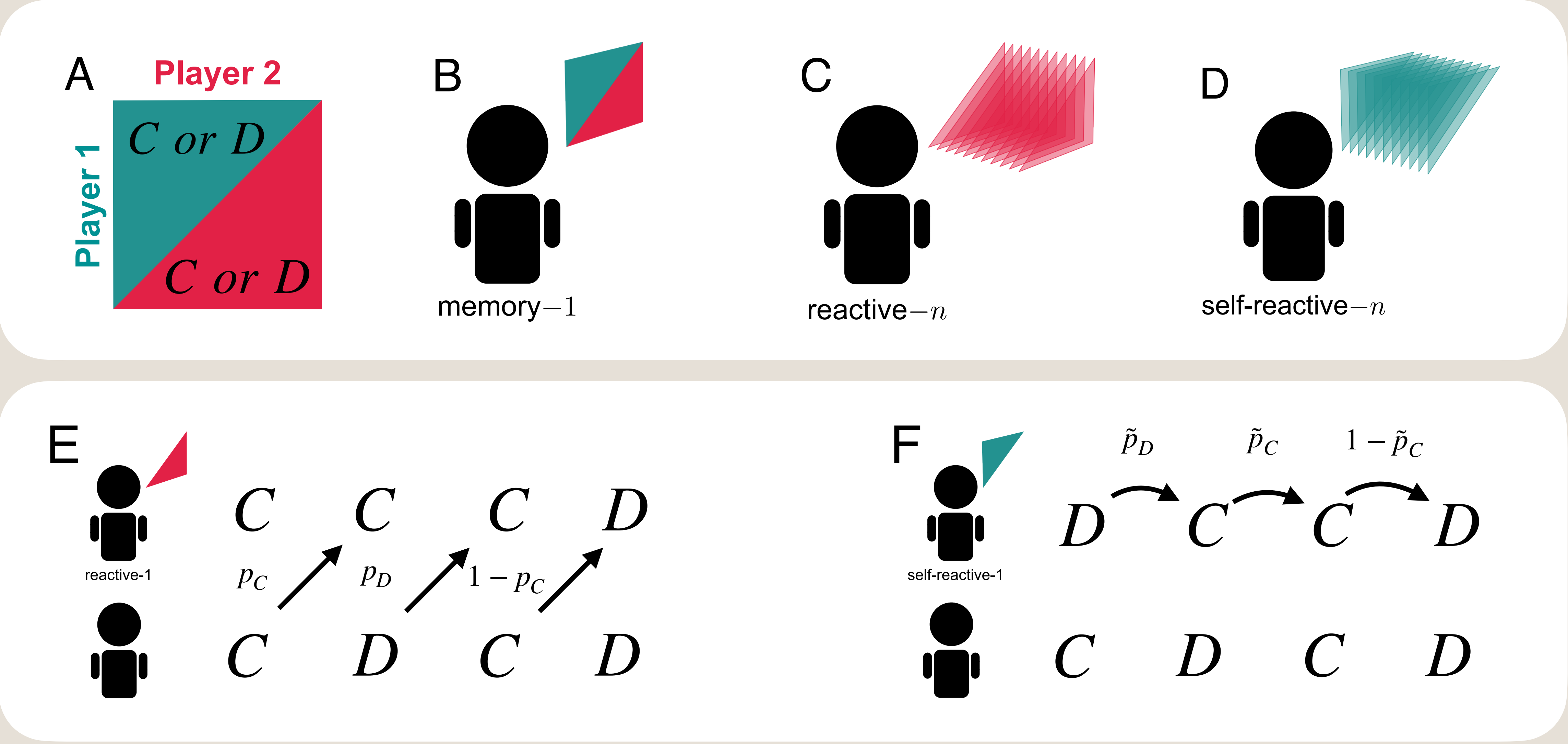


Theorem 4.10. Stable reactive-2 strategies

A nice reactive-2 strategy $\mathbf{q} = (q_{CC}, q_{CD}, q_{DC}, q_{DD})$ forms a Nash equilibrium (in the repeated donation game) if and only if

$$q_{CC} = 1, \qquad \frac{q_{CD} + q_{DC}}{2} \leq 1 - \frac{1}{2}\frac{c}{b}, \qquad q_{DD} \leq 1 - \frac{c}{b}.$$

The impact of memory: Reactive-n strategies

Definition 4.7. Reactive-n strategies

A memory-n strategy $\mathbf{q}$ is called reactive, if it only depends *on the co-player's* last n decisions.

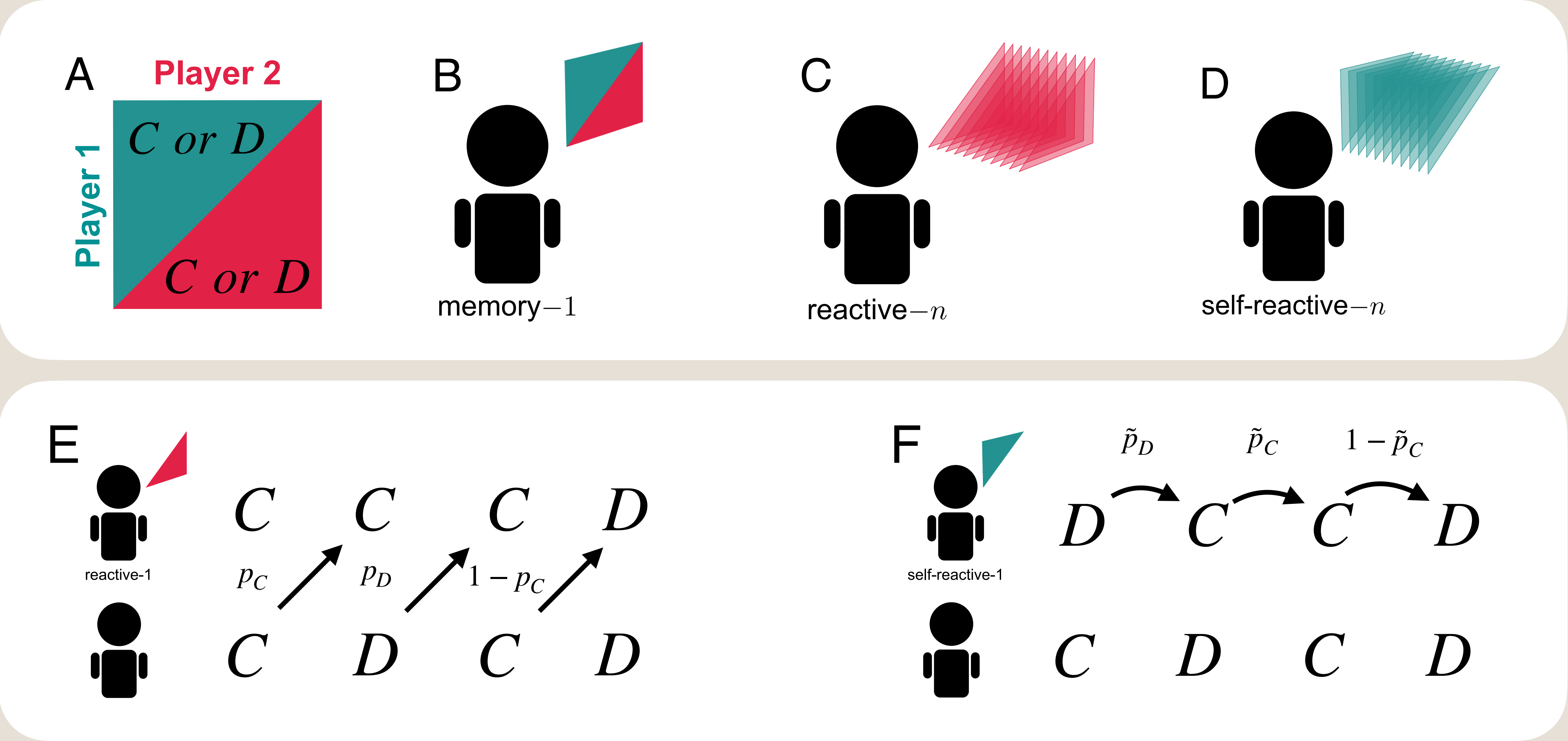
Example 4.8. Some reactive-n strategies

- Reactive-1 strategies: $\mathbf{q} = (q_C, q_D)$
  ALLD = (0,0), ALLC=(1,1), TFT = (1,0).
- Reactive-2 strategies: $\mathbf{q} = (q_{CC}, q_{CD}, q_{DC}, q_{DD})$
  Tit-for-Two-Tat = (1,1,1,0).

Theorem 4.9. Best responses against reactive-n players

To any memory-n strategy $\mathbf{q}$, one can find a best response $\tilde{\mathbf{q}}$ among the pure self-reactive-n strategies.

[In fact, if the game is a donation game, there is a best response $\tilde{\mathbf{q}}$ among the pure self-reactive-(n-1) strategies.]



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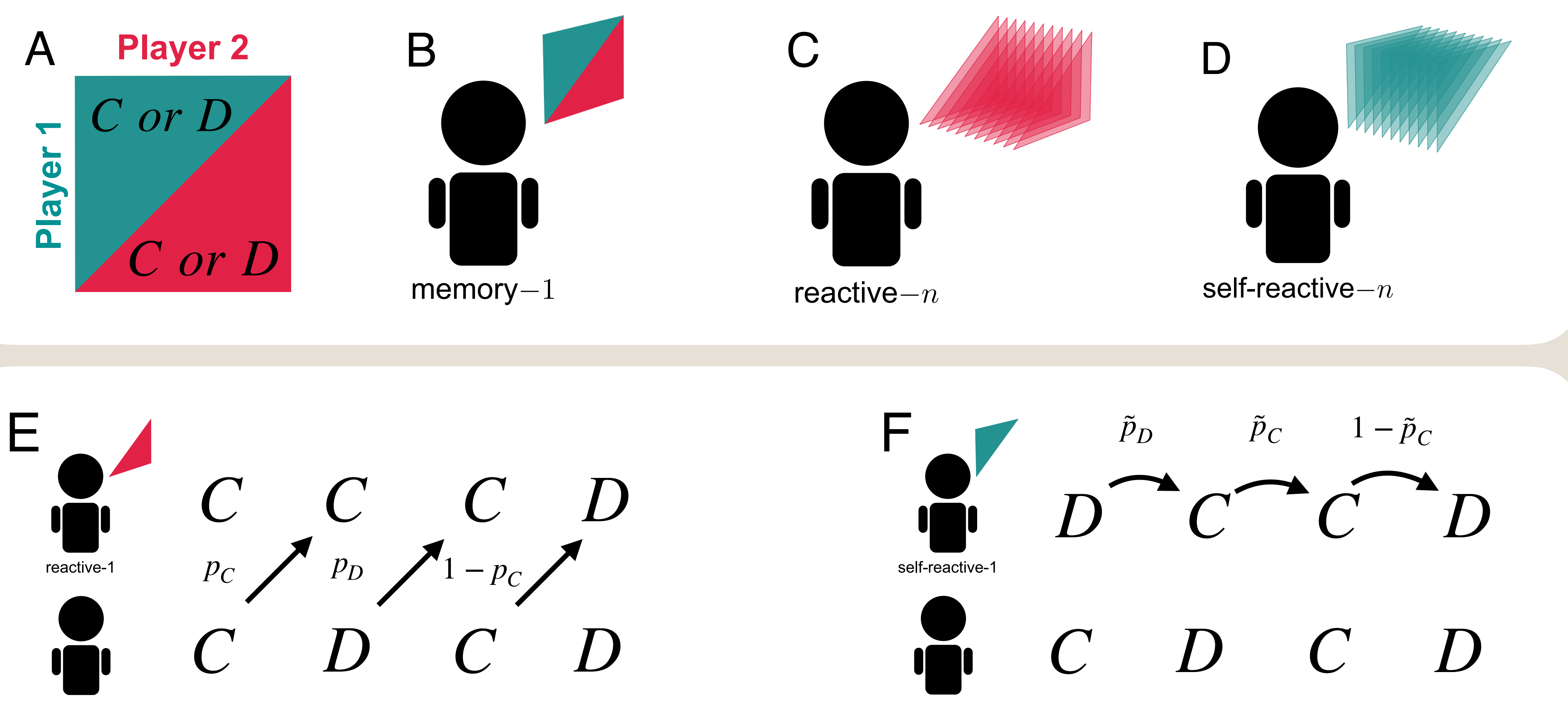
In particular,

- For every defection in memory, you reduce your cooperation probability proportionally.
- The exact timing of your defections does not matter.

The impact of memory: Reactive-n strategies



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One can derive similar conditions for reactive-3 (reactive-n).

The impact of memory: Reactive-n strategies

Remark 4.11. Evolution of Reactive-n strategies

- Consider a population of size N
- Players adopt reactive-n strategies
- They play against all other population members to get a payoff
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What is the effect of memory on evolving cooperation rates?

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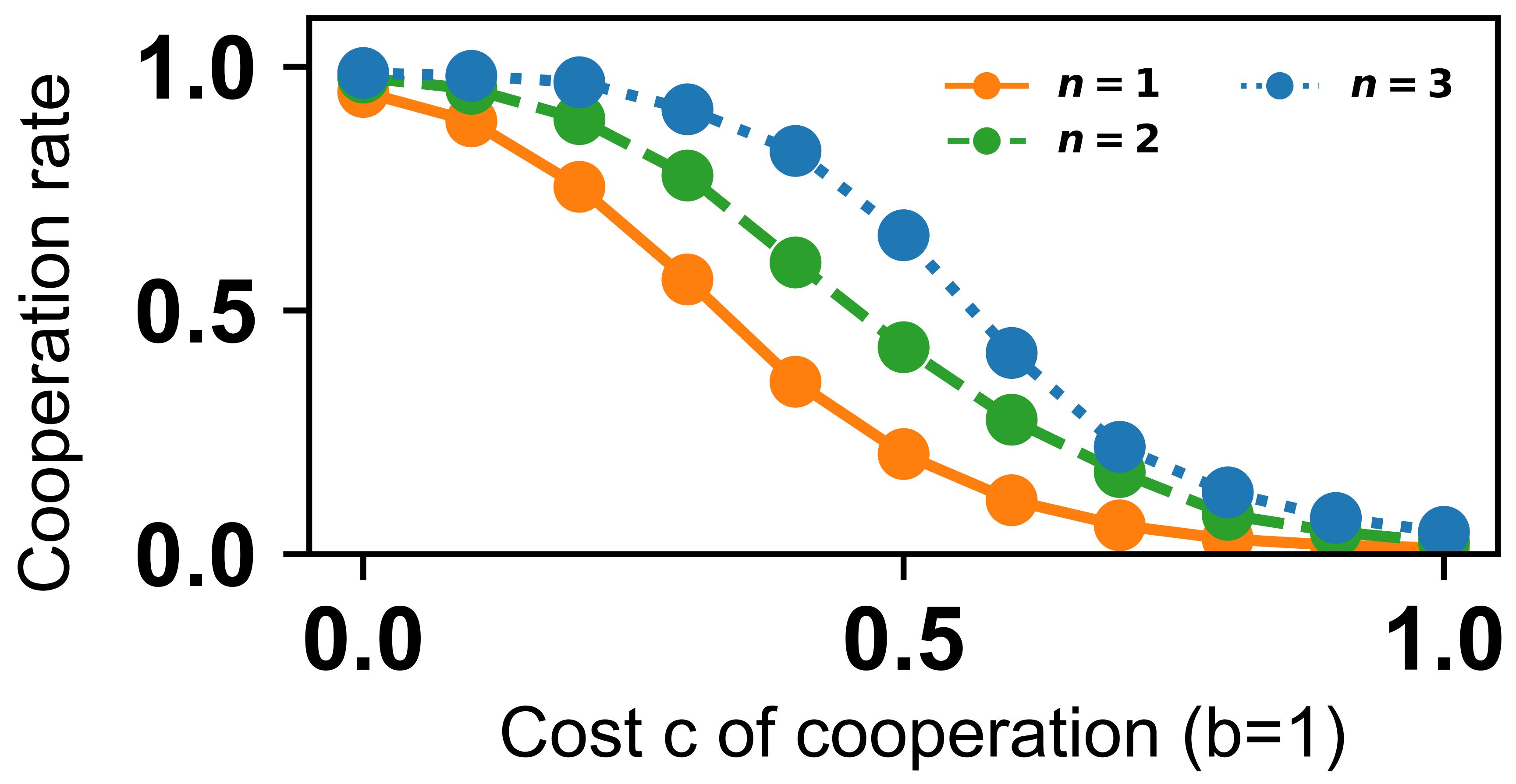

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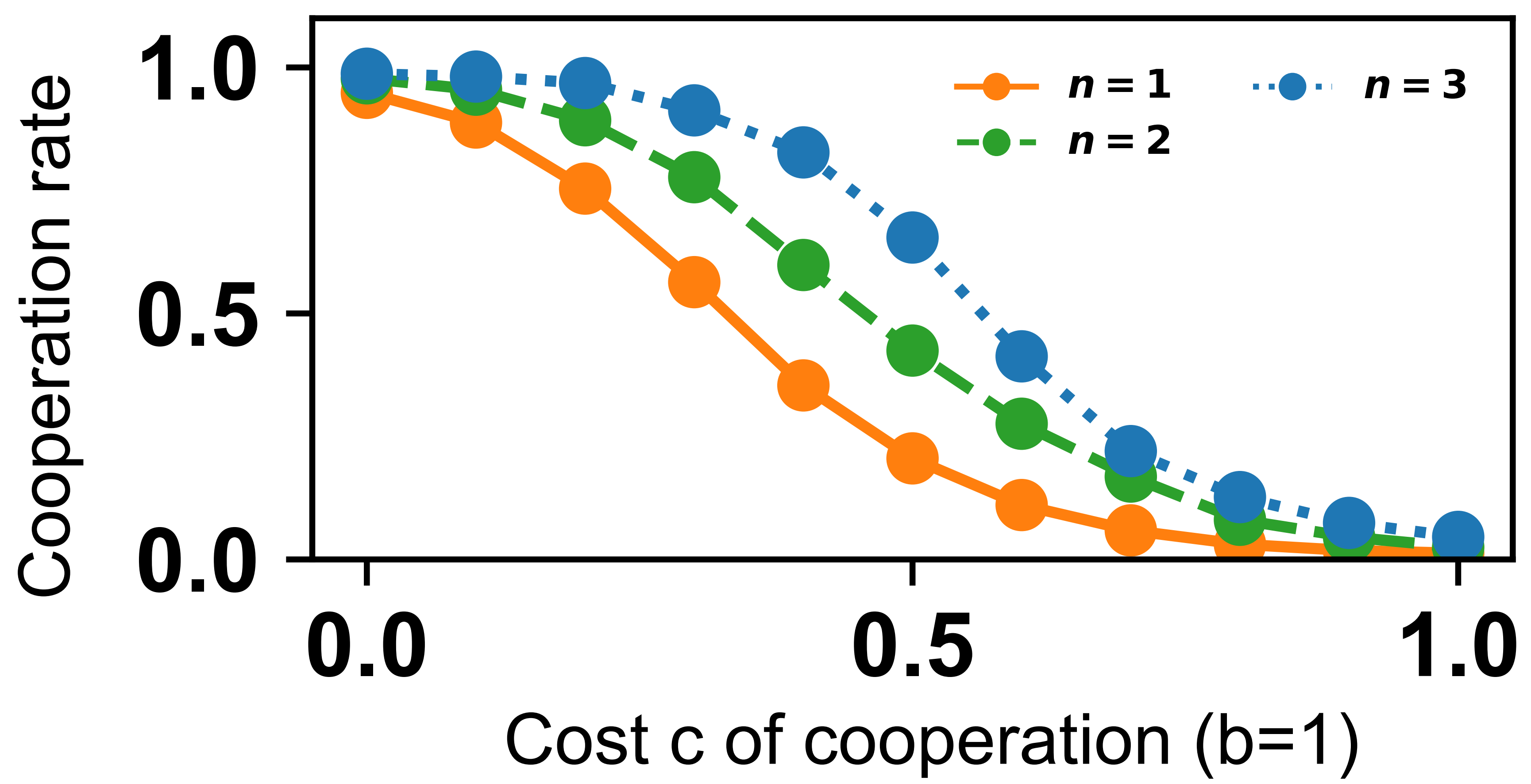


Remark 4.12. Summary

- It is interesting to explore the impact of memory capacities on direct reciprocity.
- A formal analysis can be tricky, because the size of the strategy space quickly explodes
- Still, some analytical results are feasible
- Simulations suggest that more memory helps cooperation.

An overview

Two days ago's class (March 11, 2025)

- An introduction to evolutionary game theory
  (Replicator dynamics, games in finite populations)

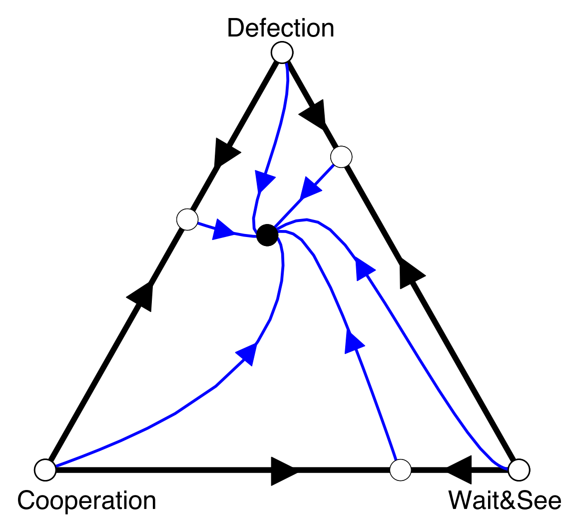
Yesterday's class (March 12, 2025)

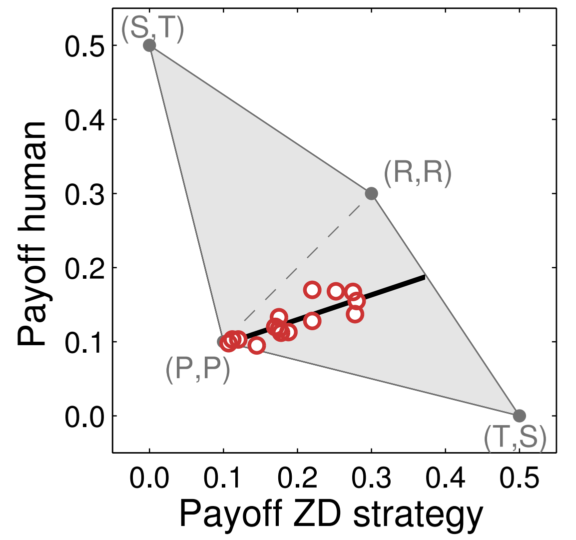
- Evolution of cooperation & direct reciprocity
- Social norms & indirect reciprocity

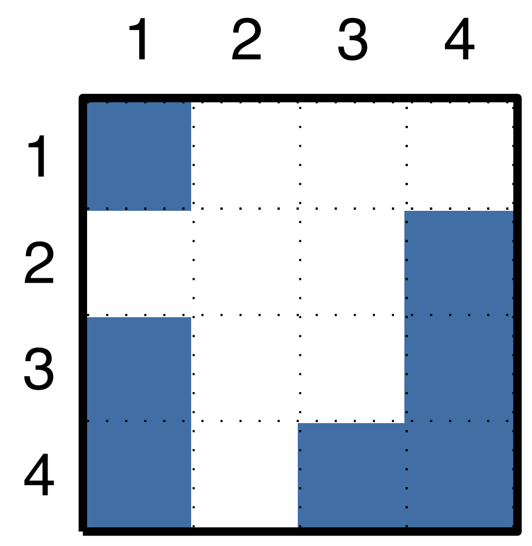
Today's class (March 13, 2025)

- Some current research: Reciprocity in complex environments

The role of memory; the effect of changing environments; the impact of inequality







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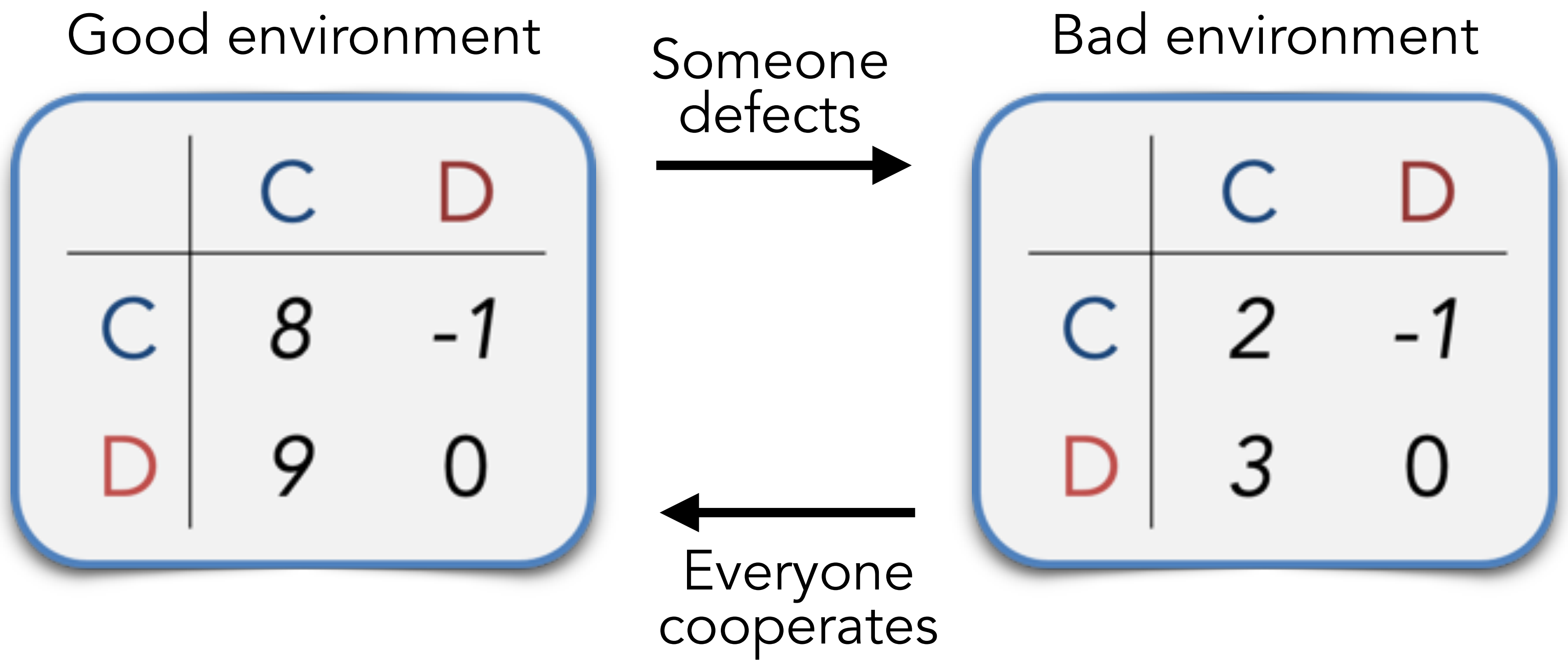

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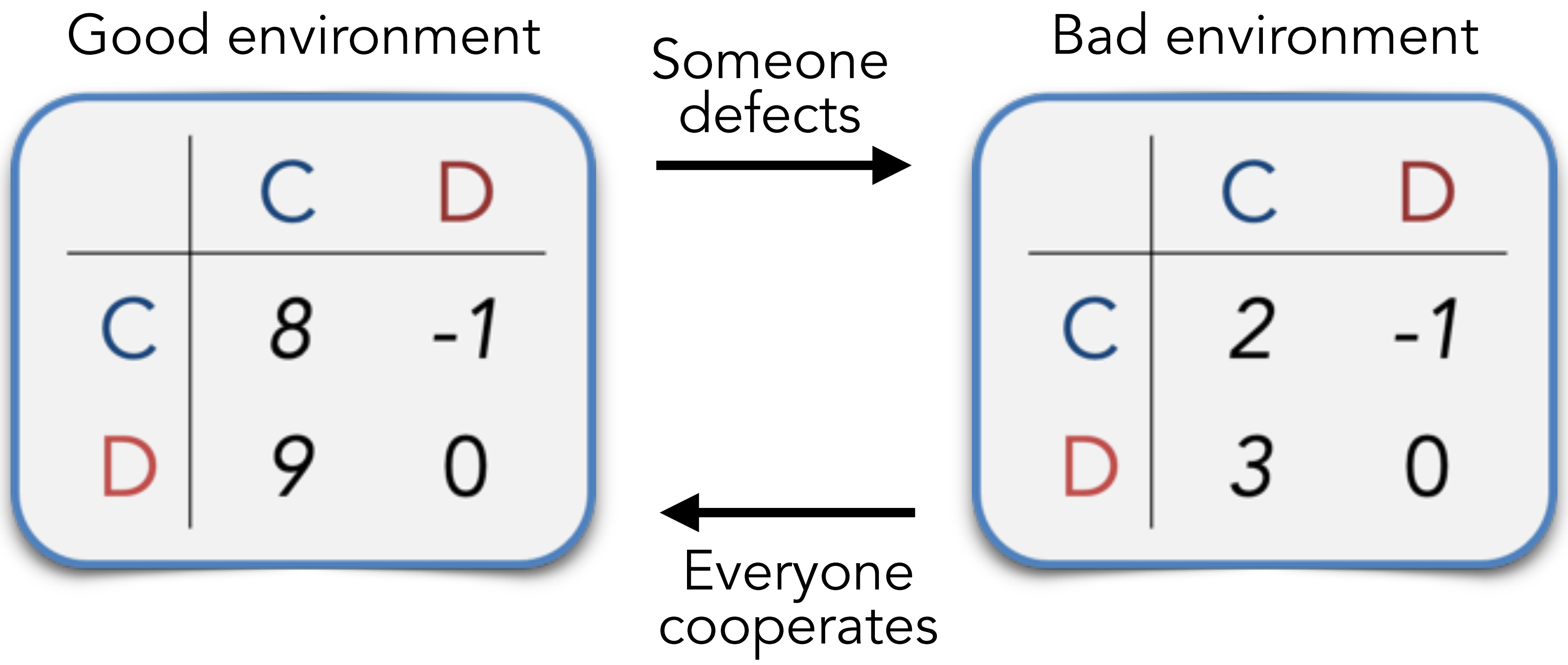

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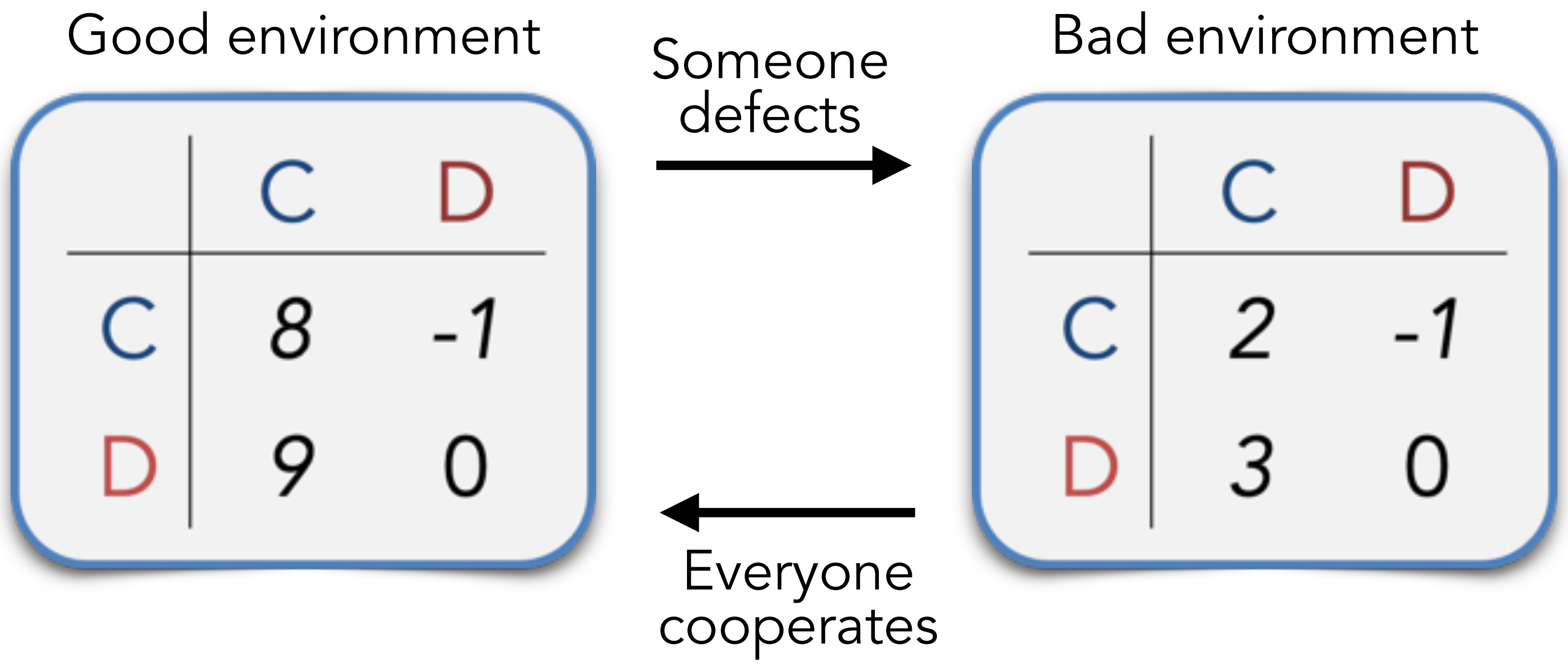

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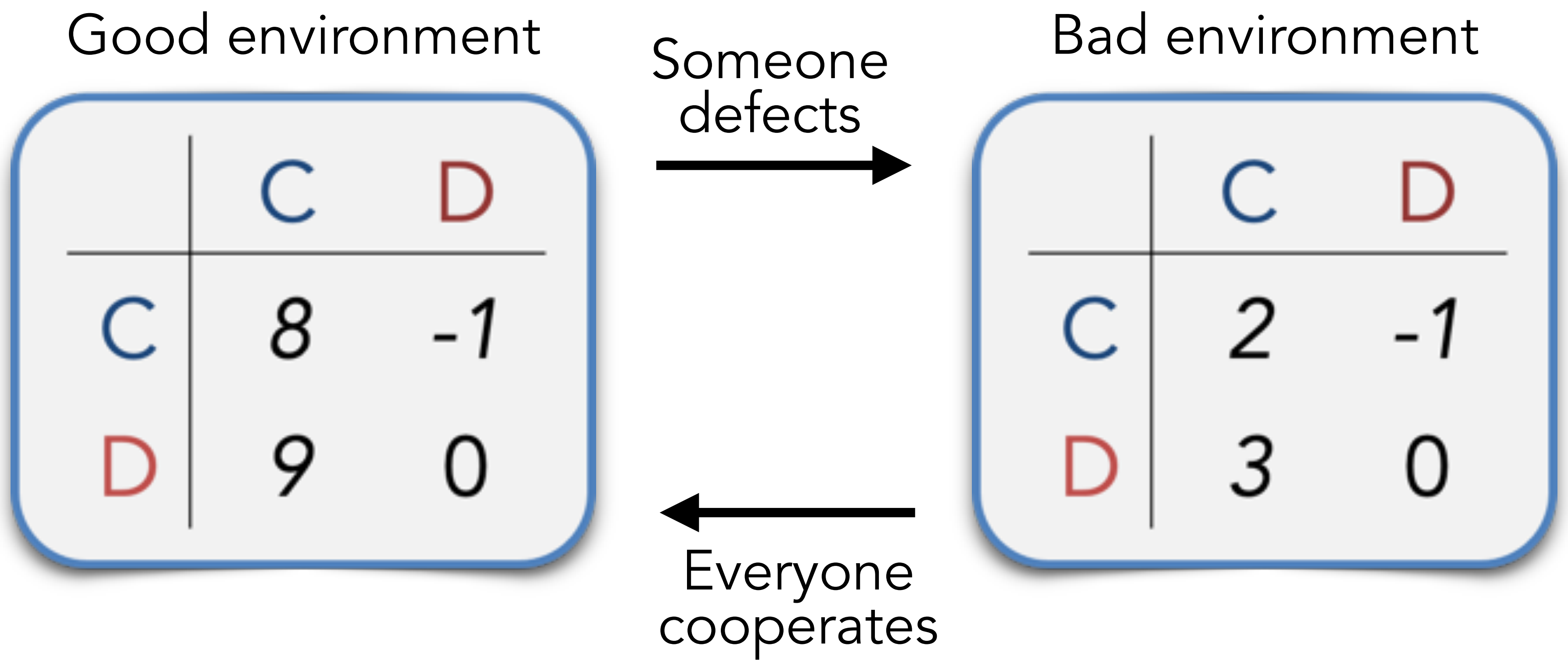

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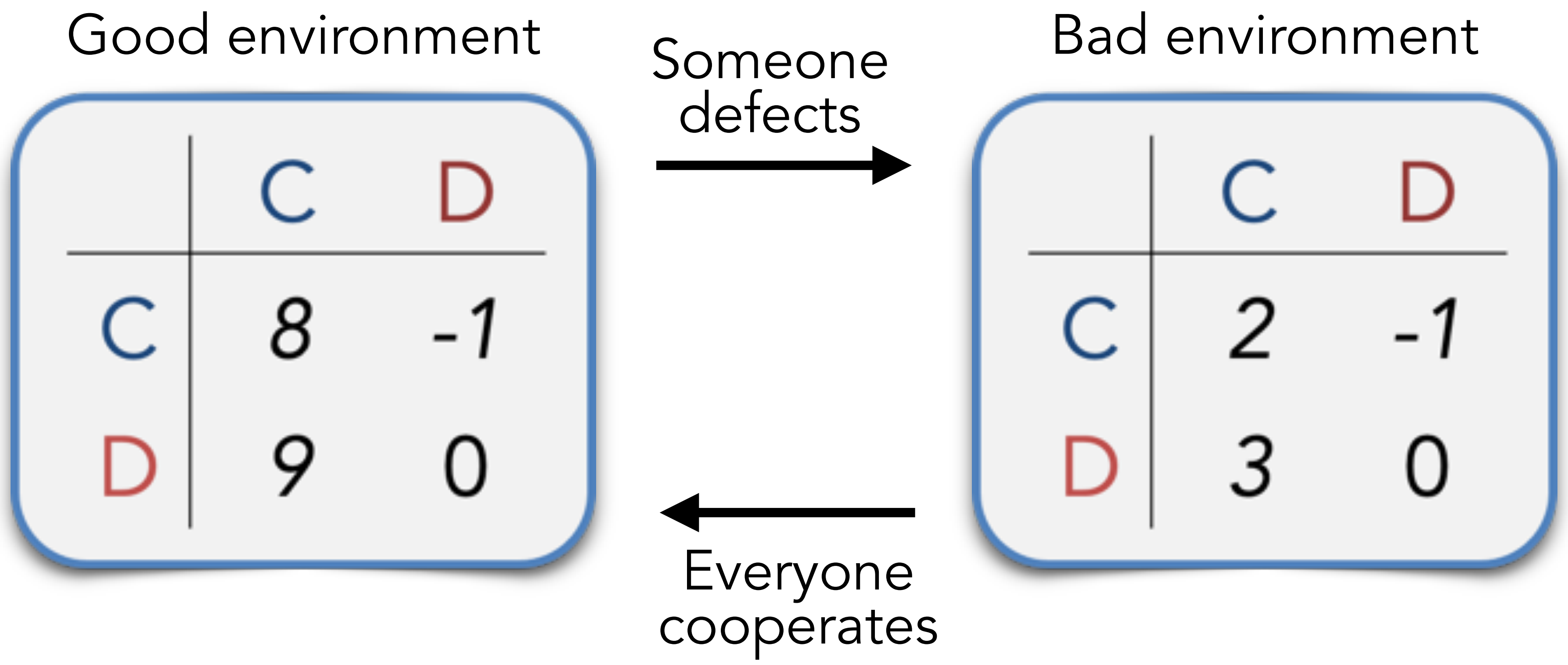

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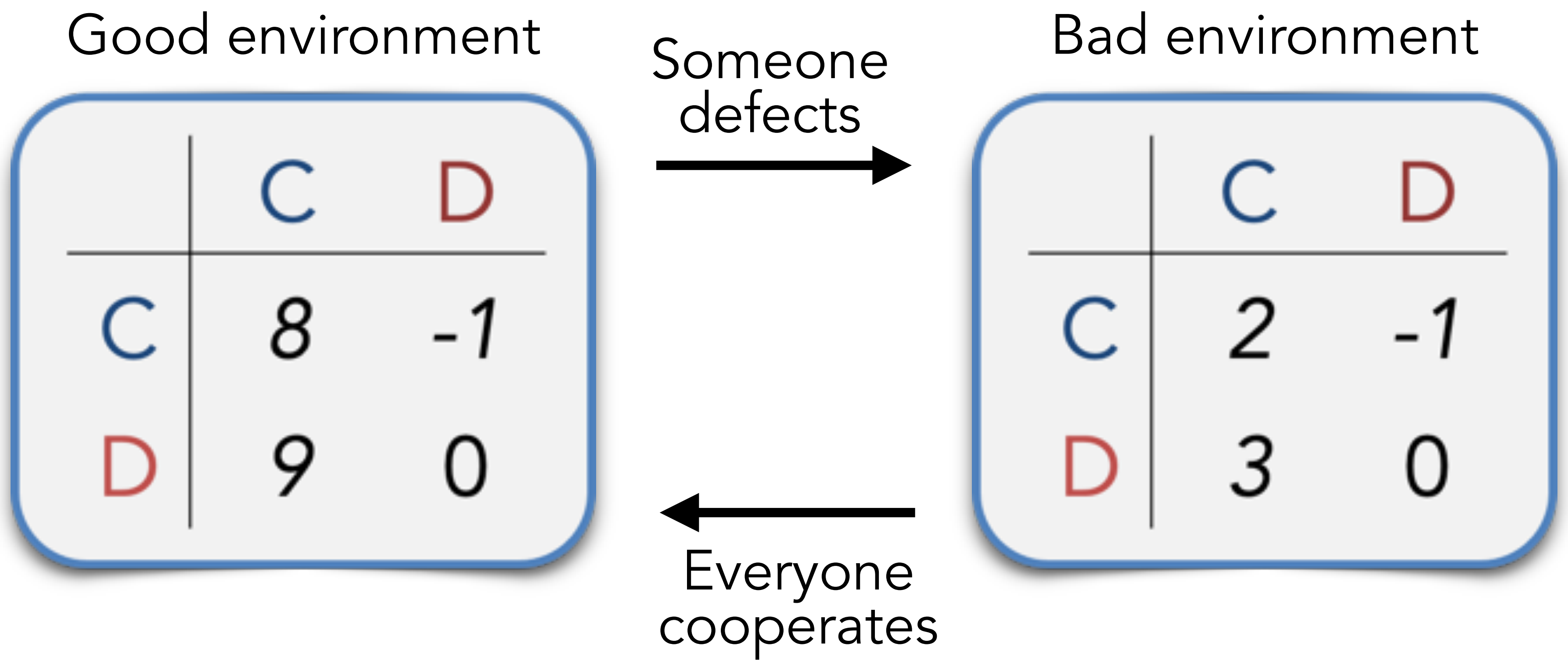

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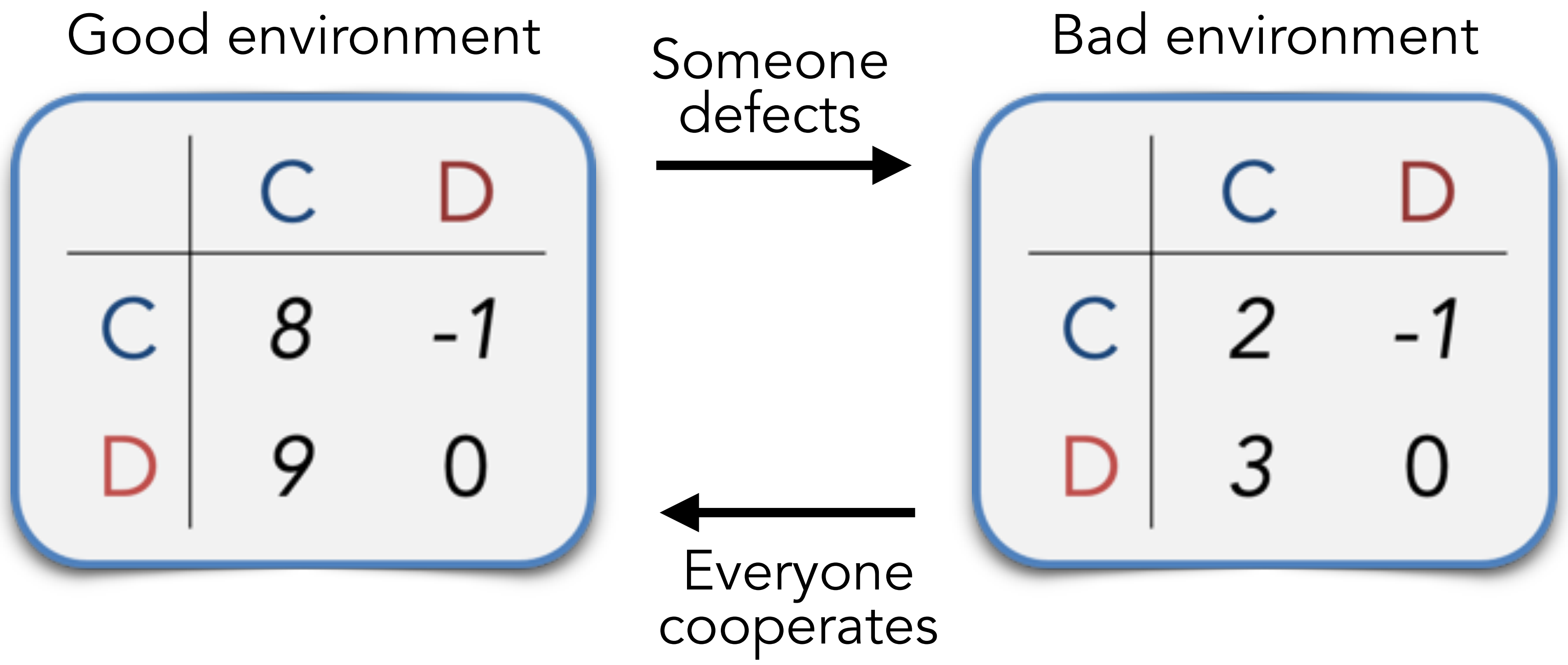

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Good environment

	C	D
C	8	-1
D	9	0

Someone defects →

← Everyone cooperates

Bad environment

	C	D
C	2	-1
D	3	0

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- A player's payoff in the stochastic game is the player's average payoff per round, $\pi_i = \lim_{T\to\infty} \frac{1}{T} \sum_{t=1}^{T} \pi_i(t)$

Evolution of cooperation in stochastic games

Example 4.15. Evolution of cooperation in stochastic games

- We consider a set of N players
- Players are randomly matched in groups of n, and then play the stochastic game against each other.

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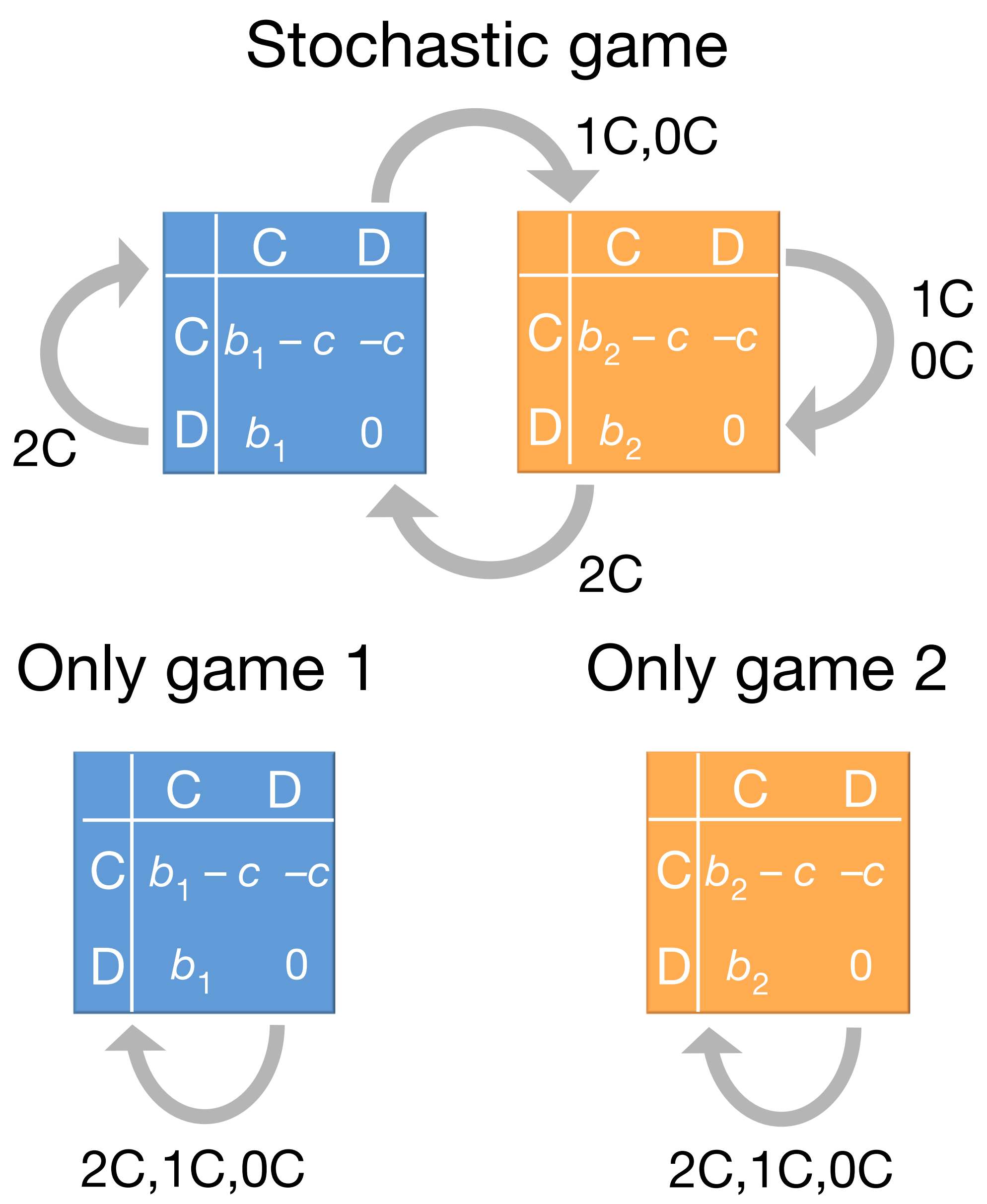

	C	D
C	$b_1 - c$	$-c$
D	b_1	0

	C	D
C	$b_2 - c$	$-c$
D	b_2	0

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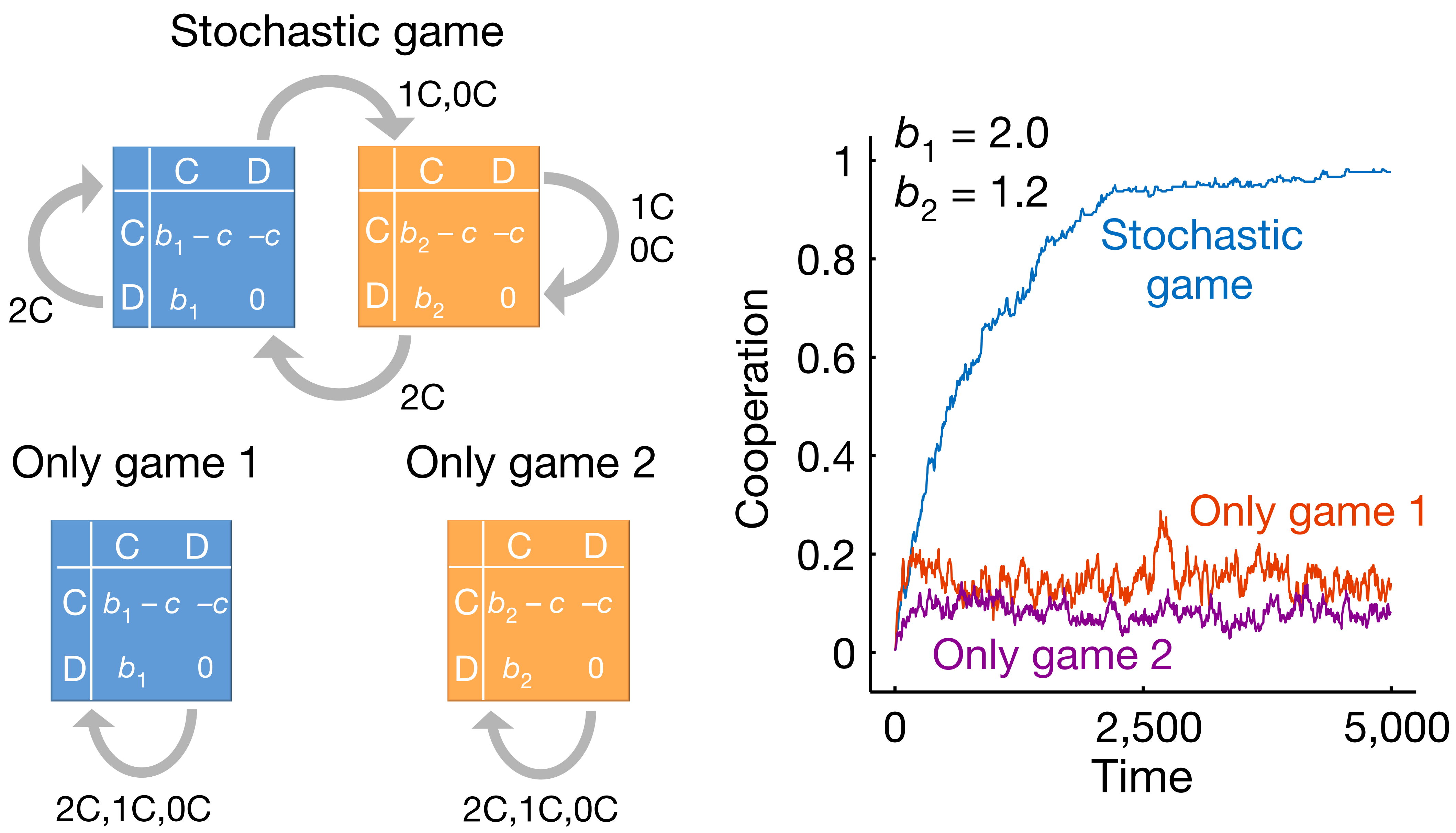

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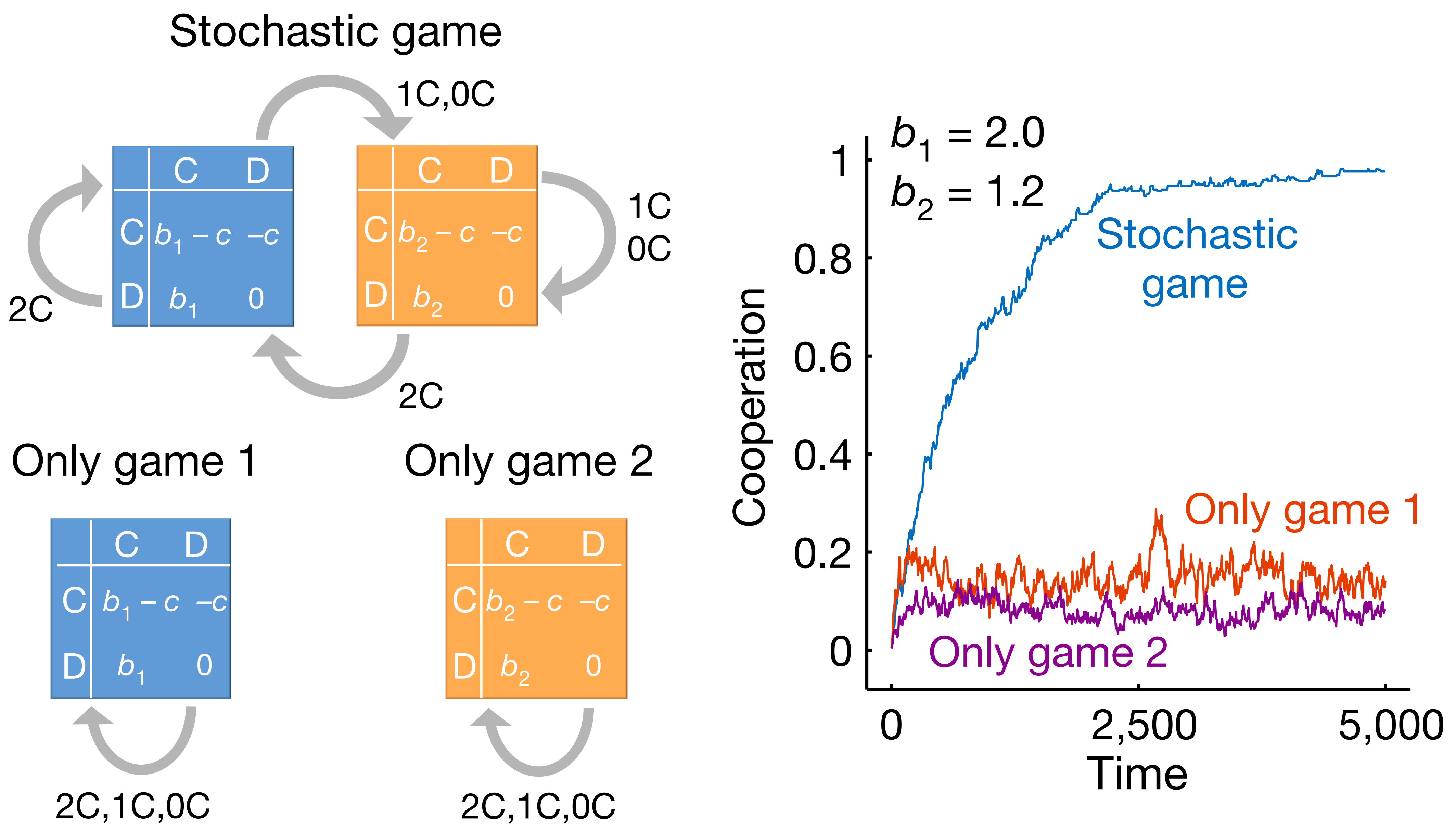
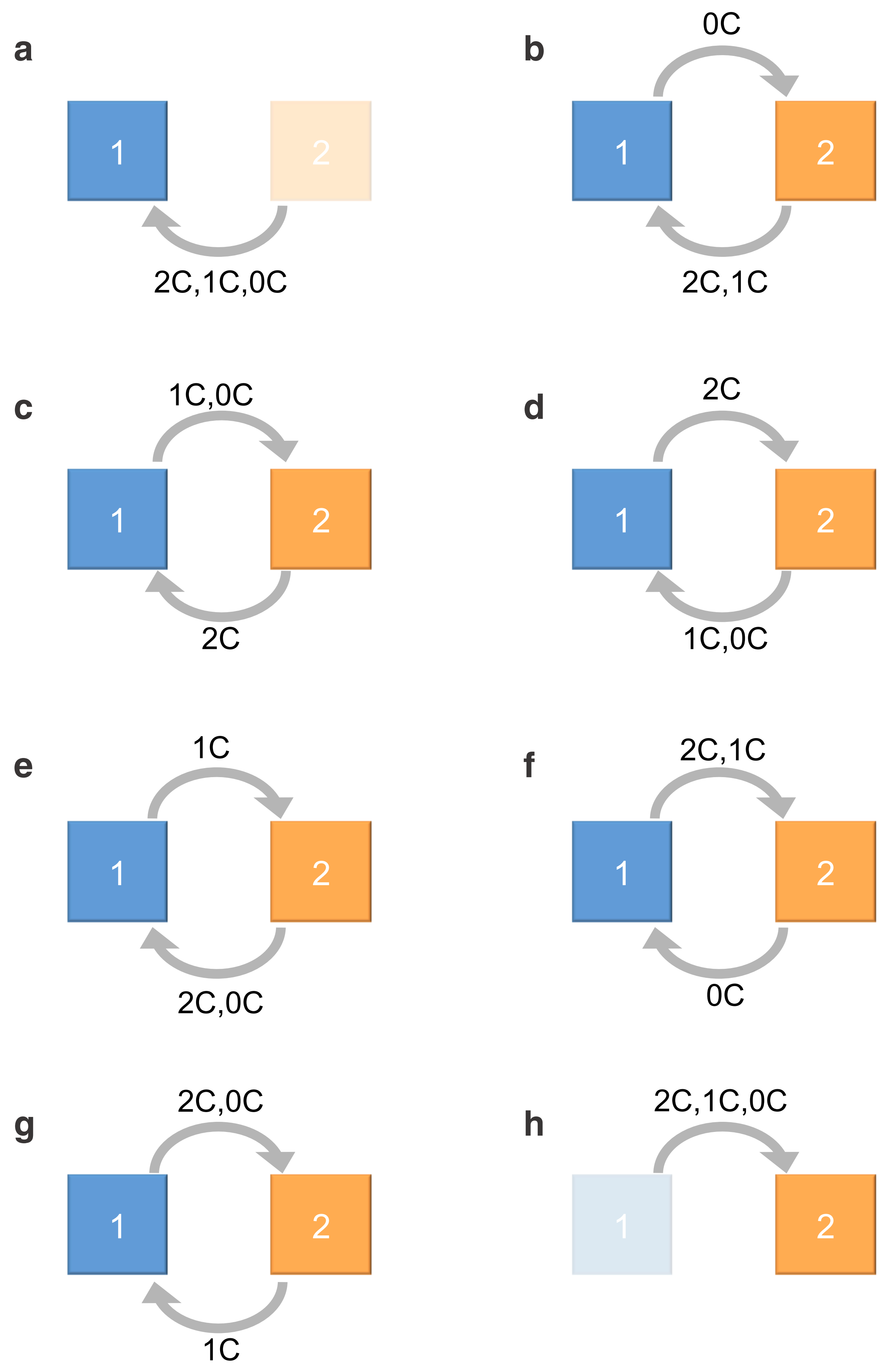


Remark 4.16. Dependence on state transitions



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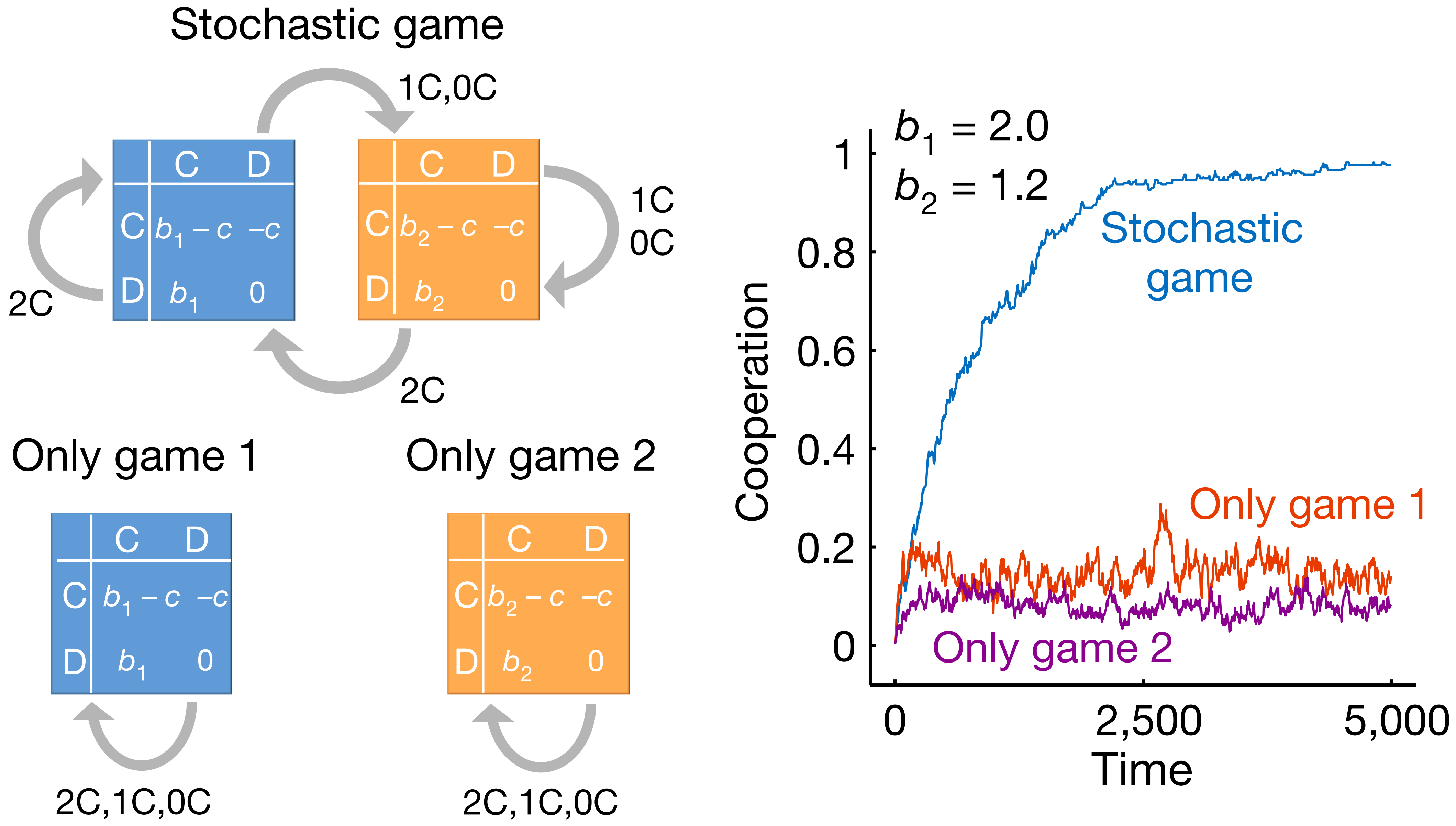

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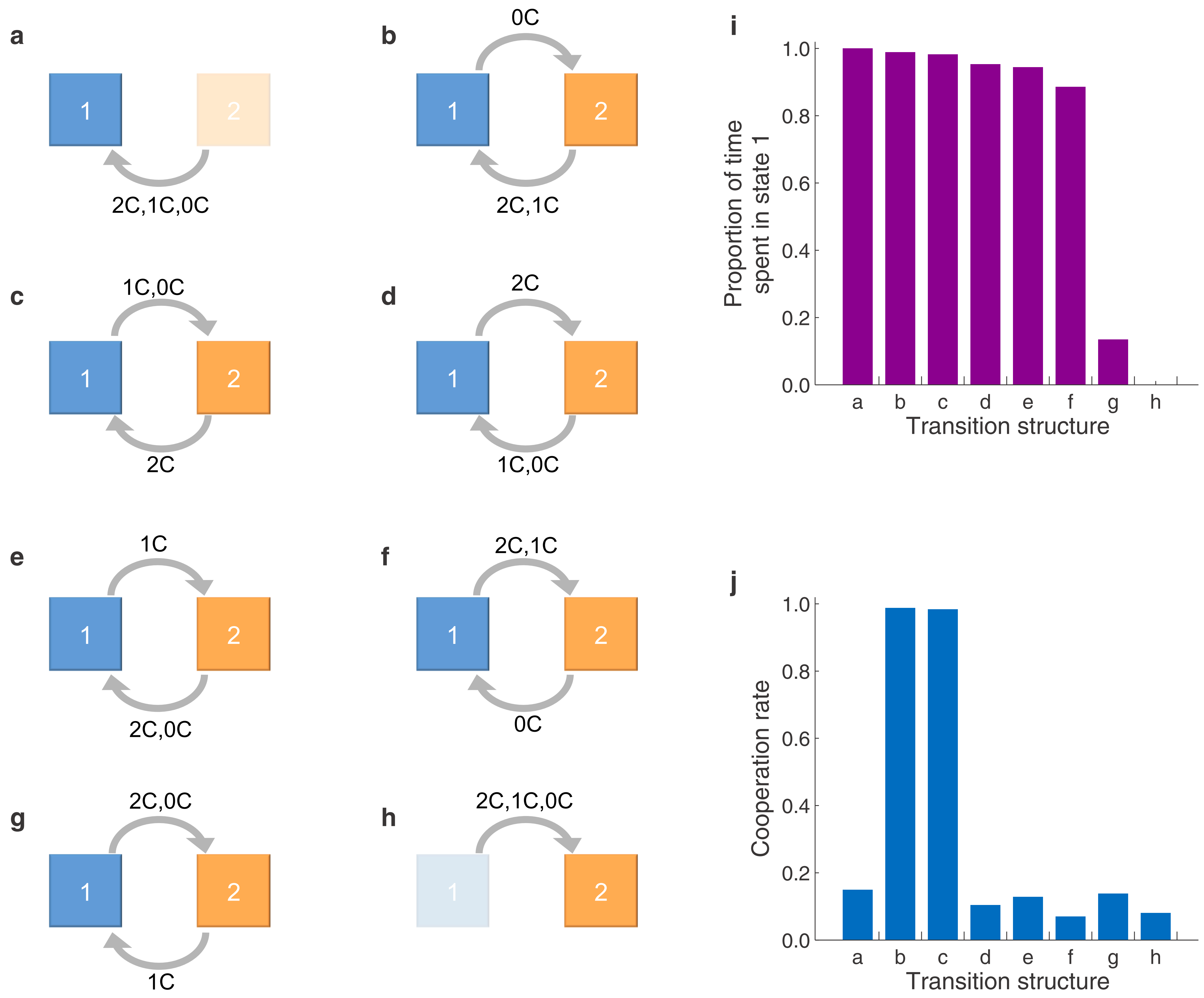

Evolution of cooperation in stochastic games

Example 4.17. Cooperation in larger groups

- Suppose now the game is played in groups of 4 players

Evolution of cooperation in stochastic games

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- We consider four different treatments, which differ in how easily the environment deteriorates (how quickly the multiplication factor decreases if few people cooperate).

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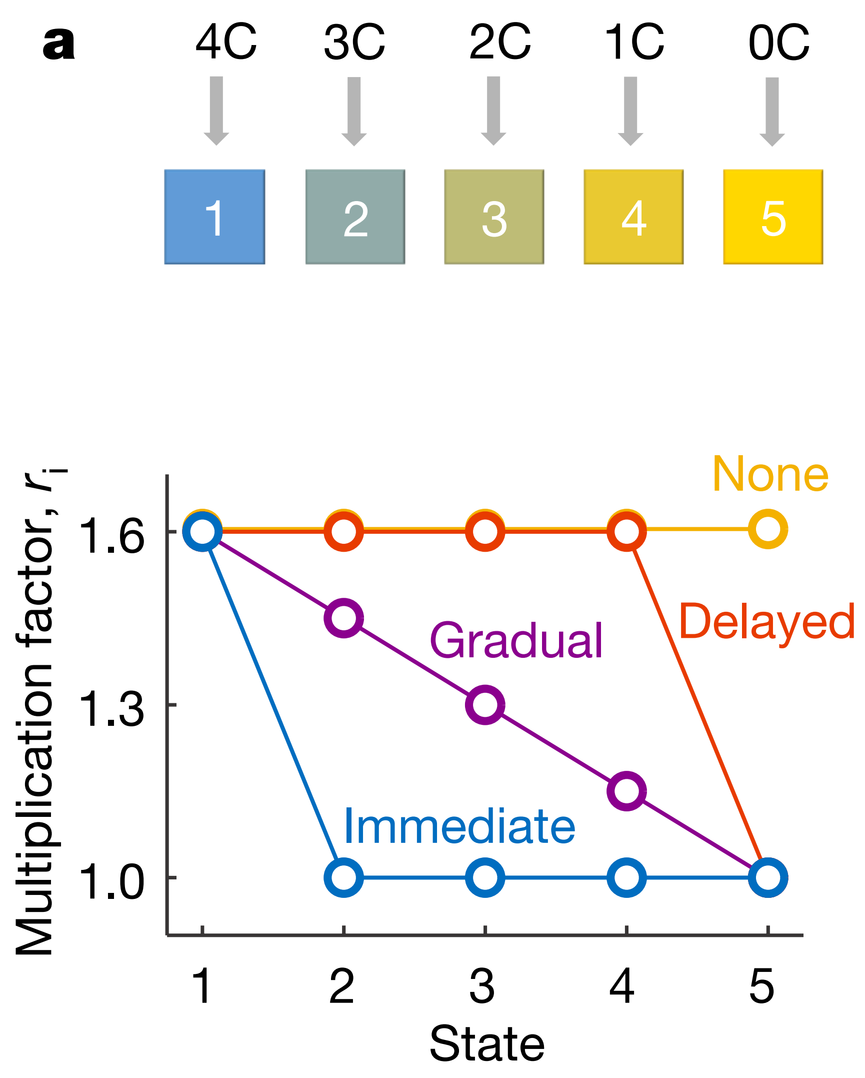

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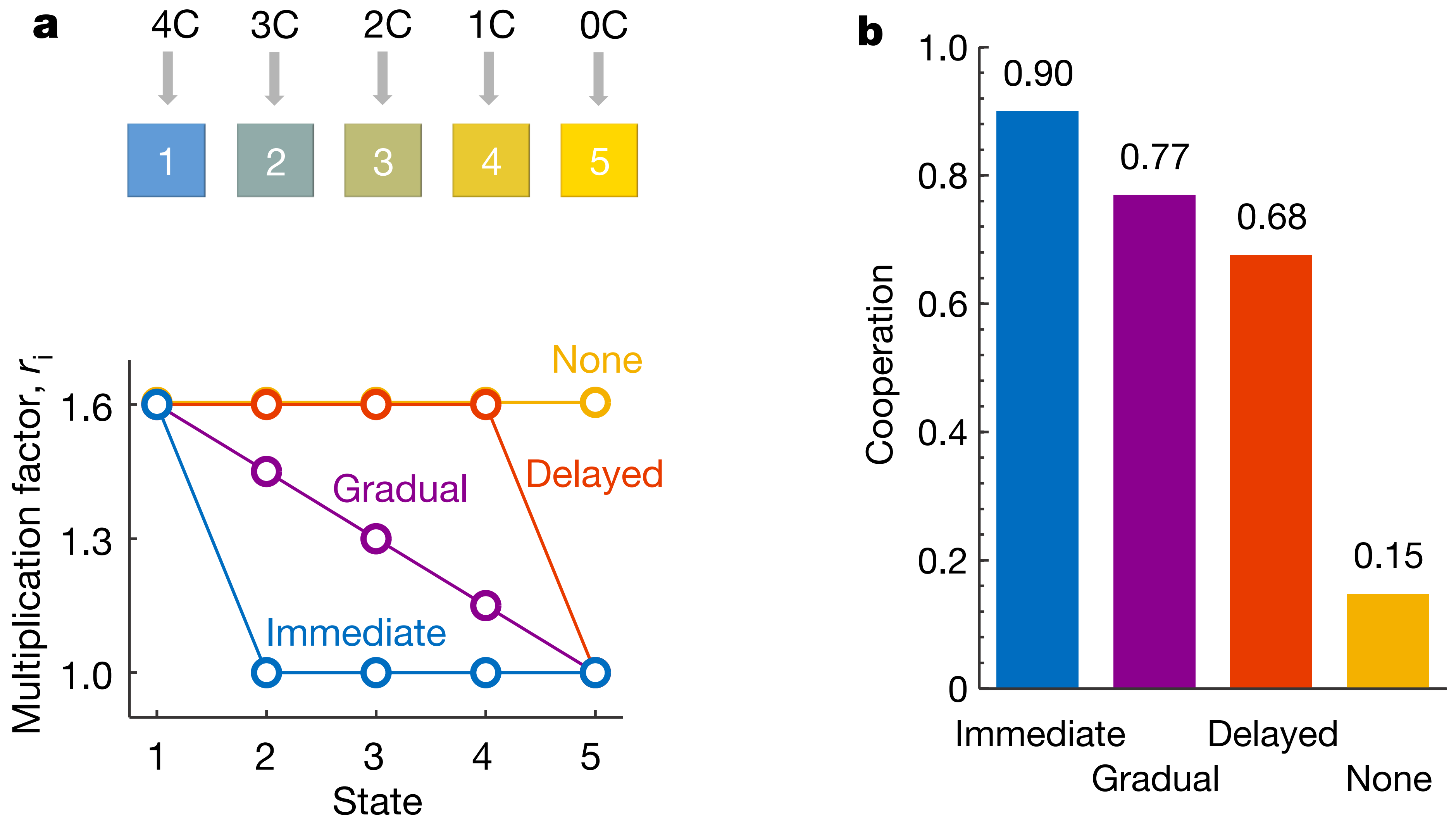

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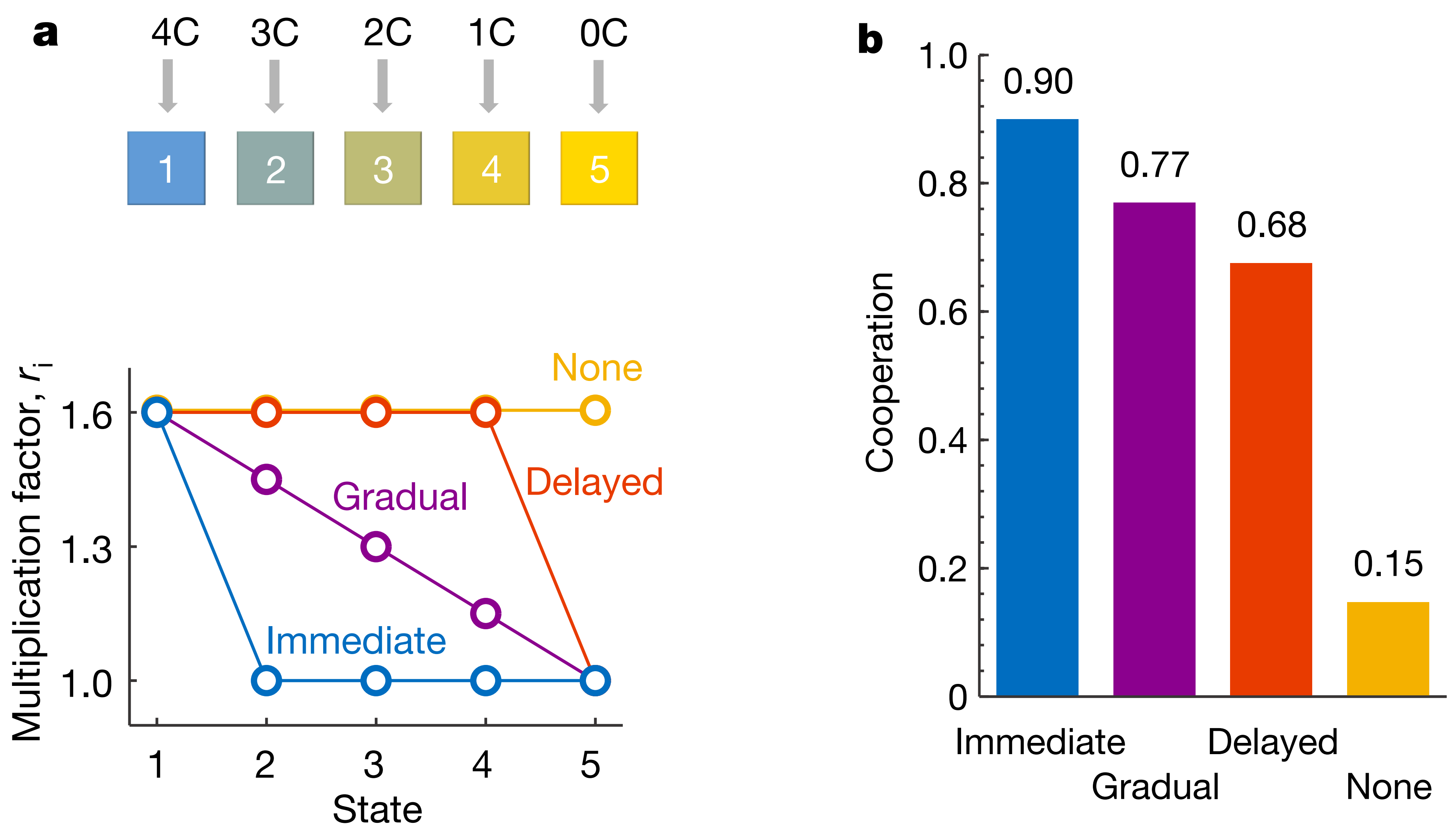

Remark 4.18. Summary

- When individual actions do not only affect payoffs, but also the players' environment, this can favour the evolution of cooperation.
- Cooperation is most favored when defection results in a quick deterioration of the environment, leading players to interact in more unprofitable games.

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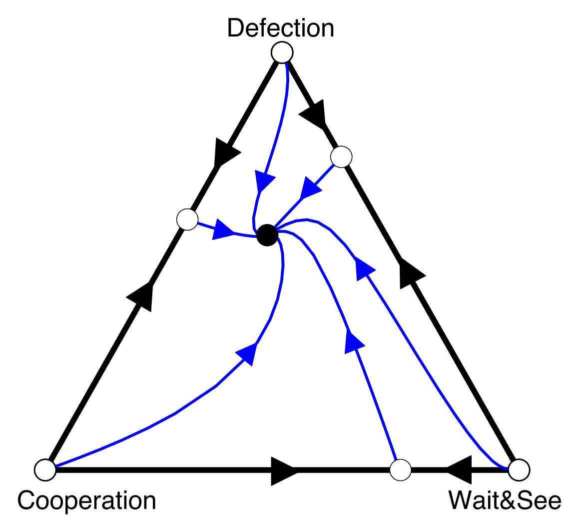
  (Replicator dynamics, games in finite populations)



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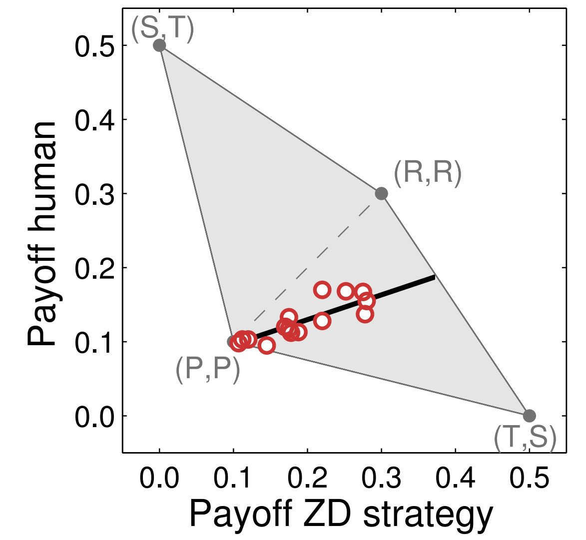

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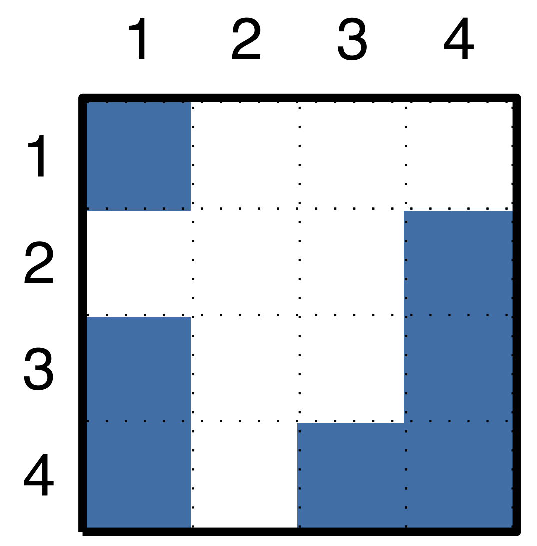
- Some current research: Reciprocity in complex environments

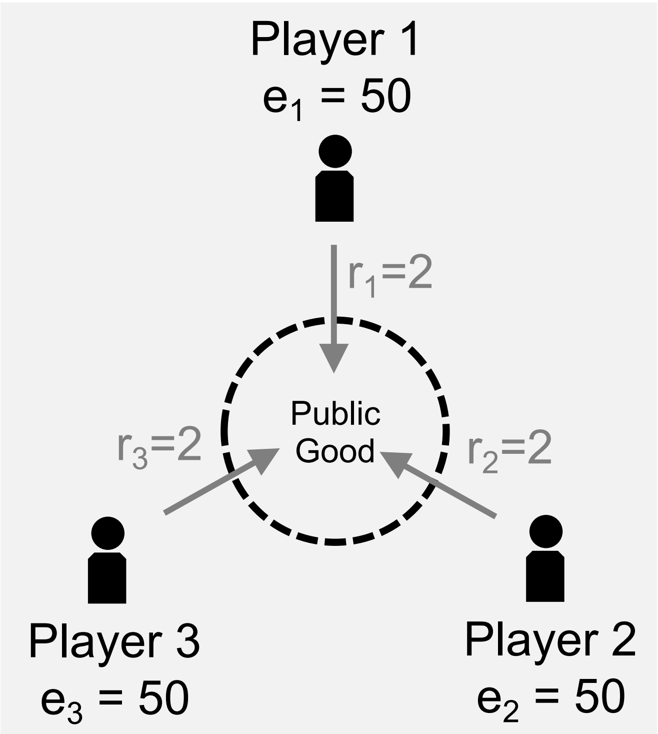
The role of memory; the effect of changing environments; the impact of inequality



Cooperation in asymmetric games

Remark 4.19. On the role of symmetric games

- In evolutionary game theory, we really like symmetric games.



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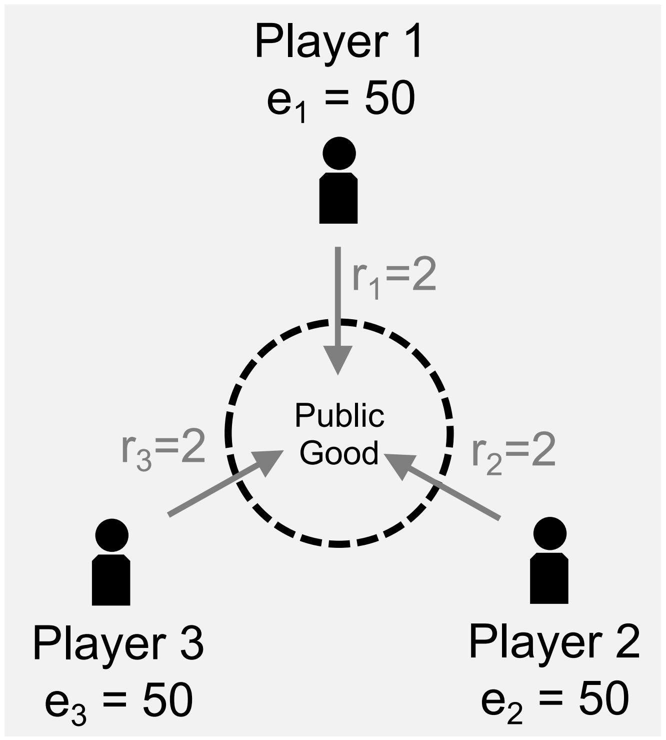

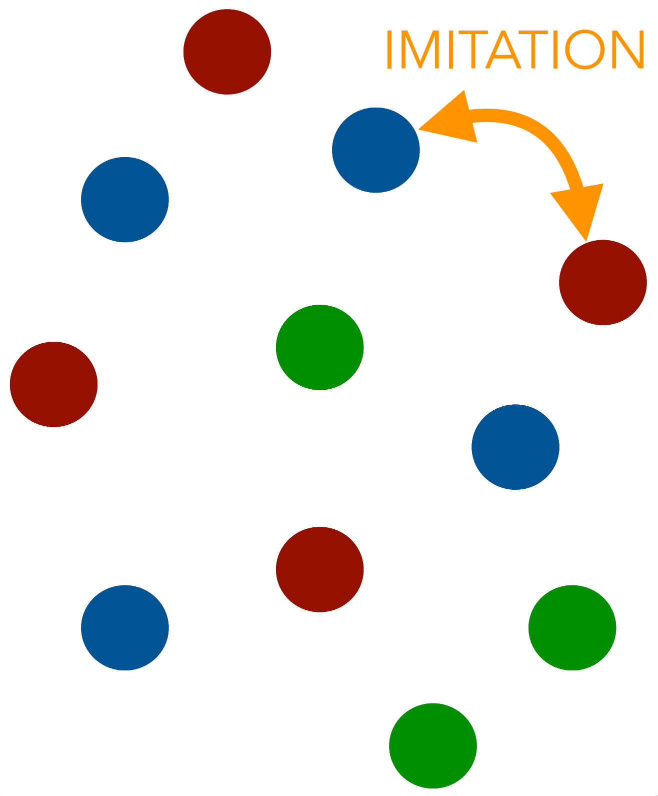

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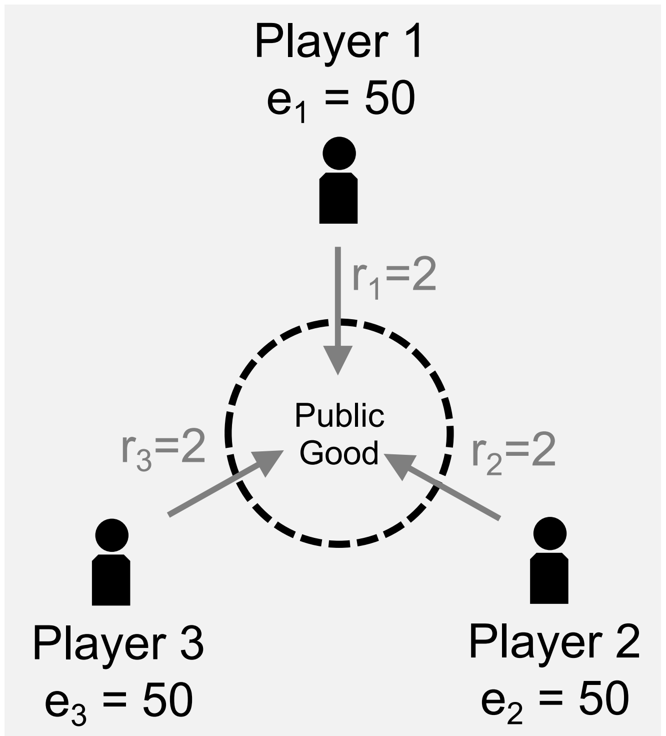

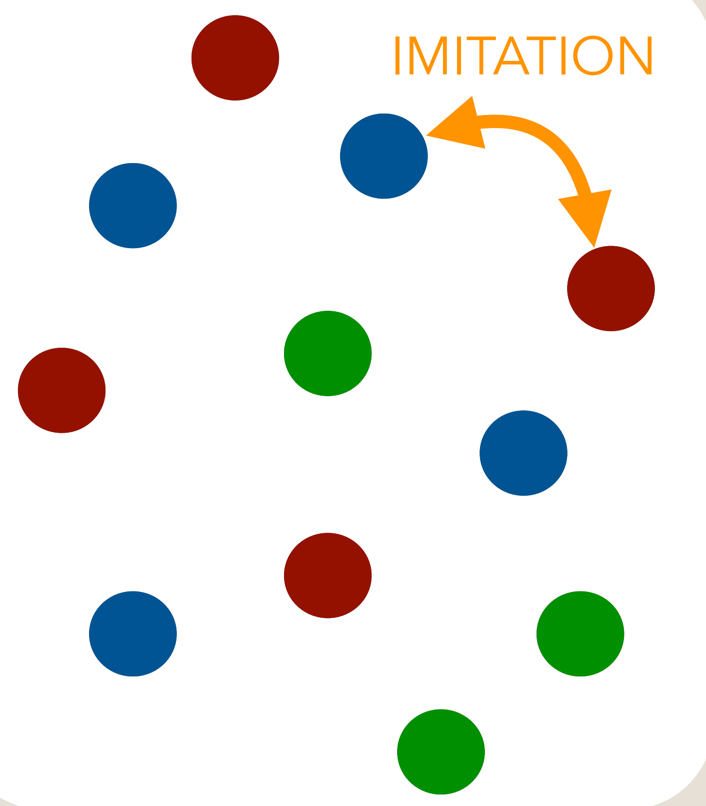

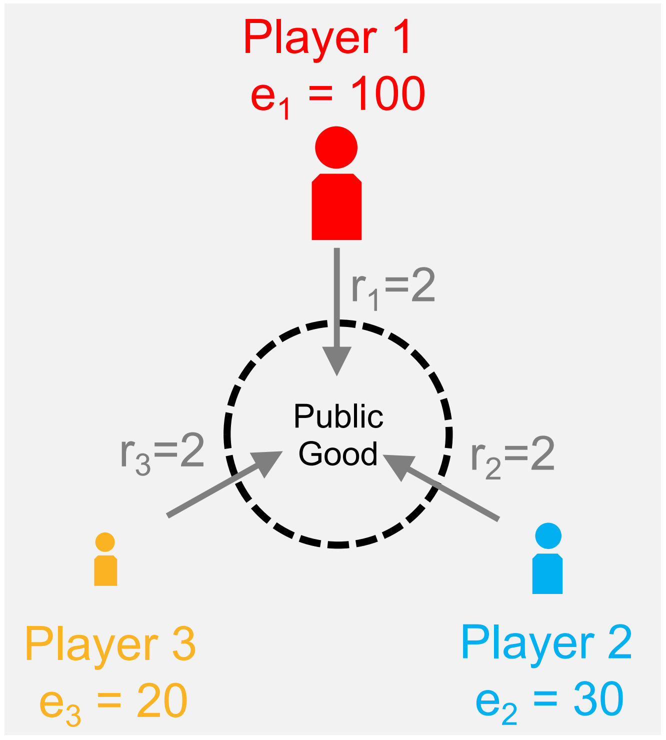

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Why asymmetry is nontrivial

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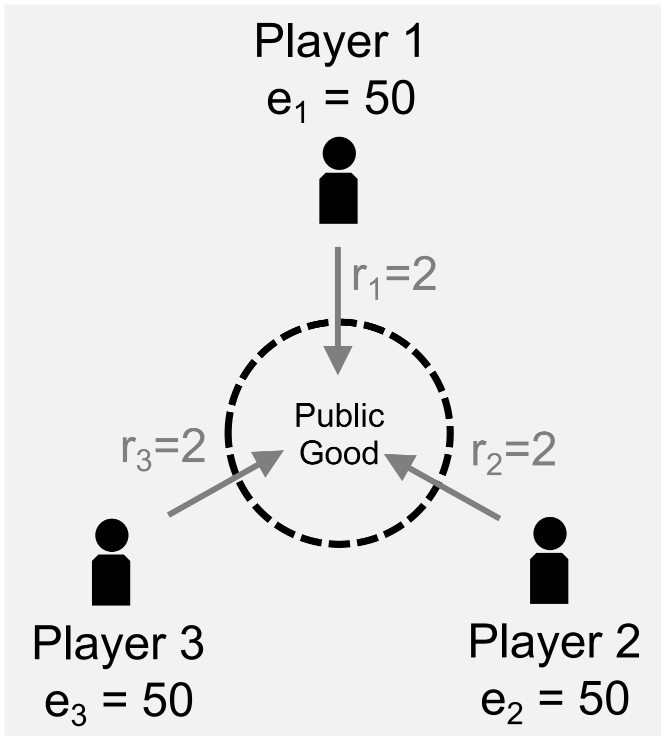

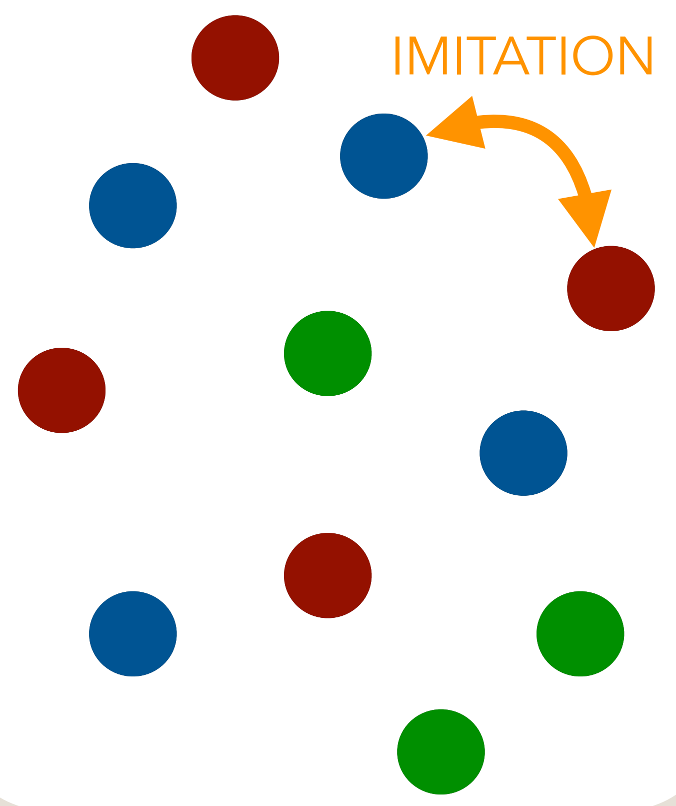

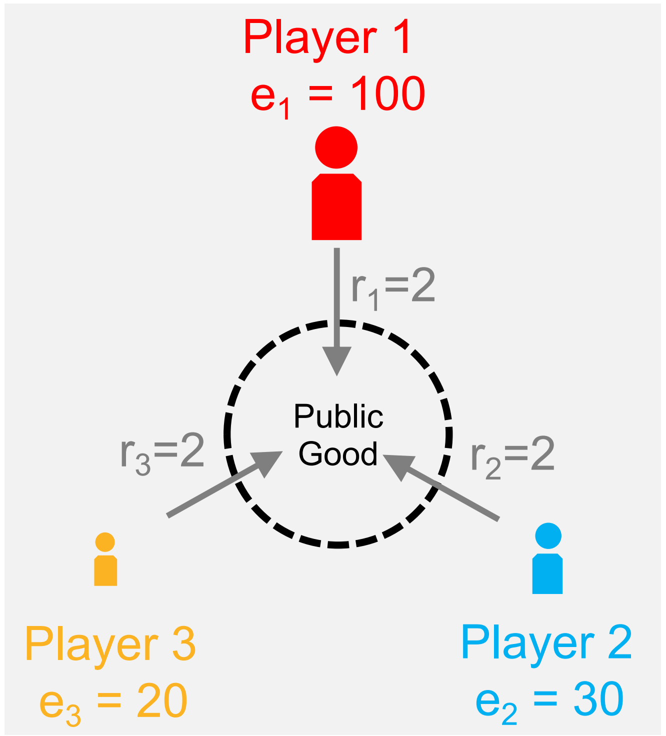

Cooperation in asymmetric games

Remark 4.19. On the role of symmetric games

- In evolutionary game theory, we really like symmetric games.
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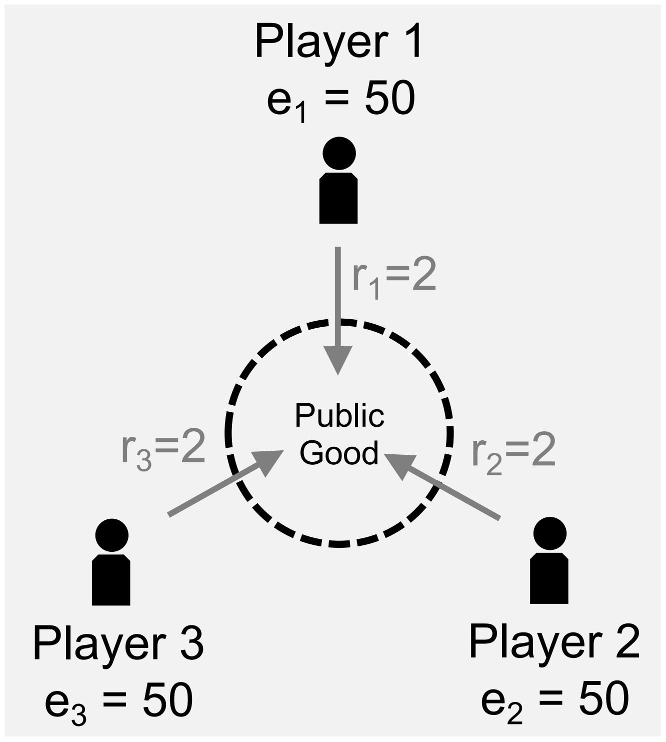

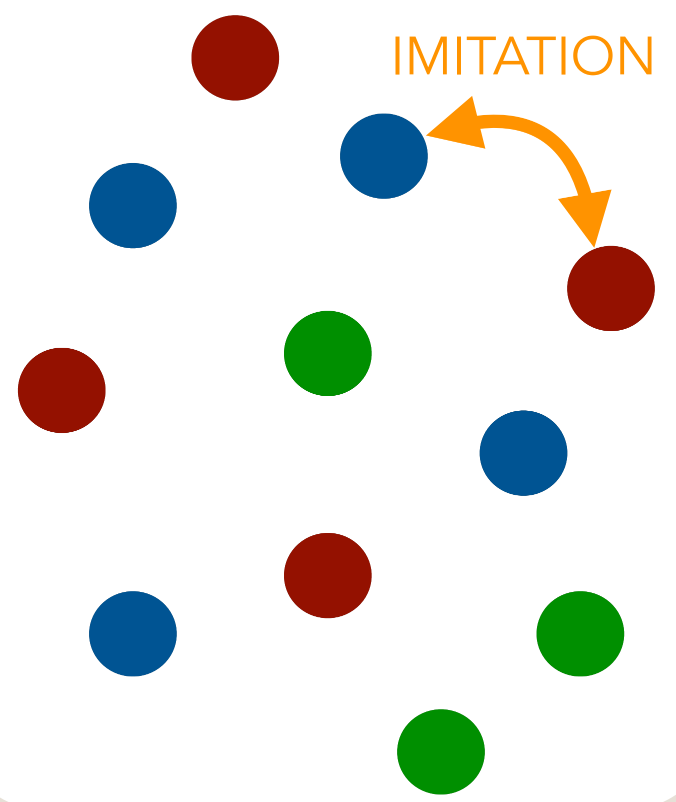

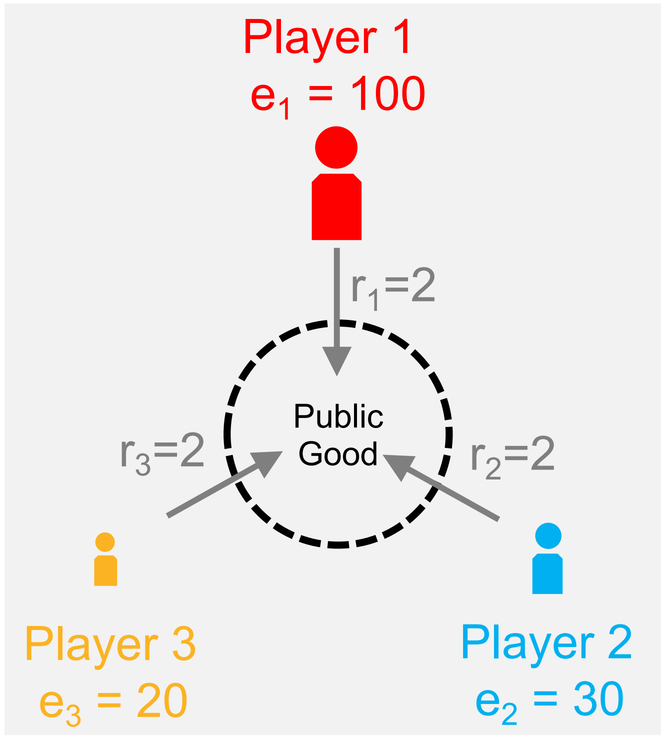

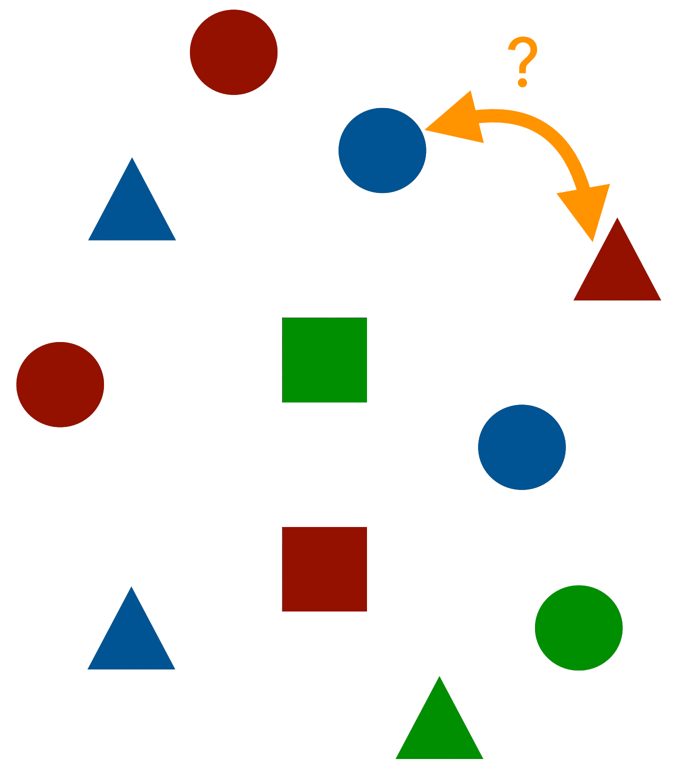

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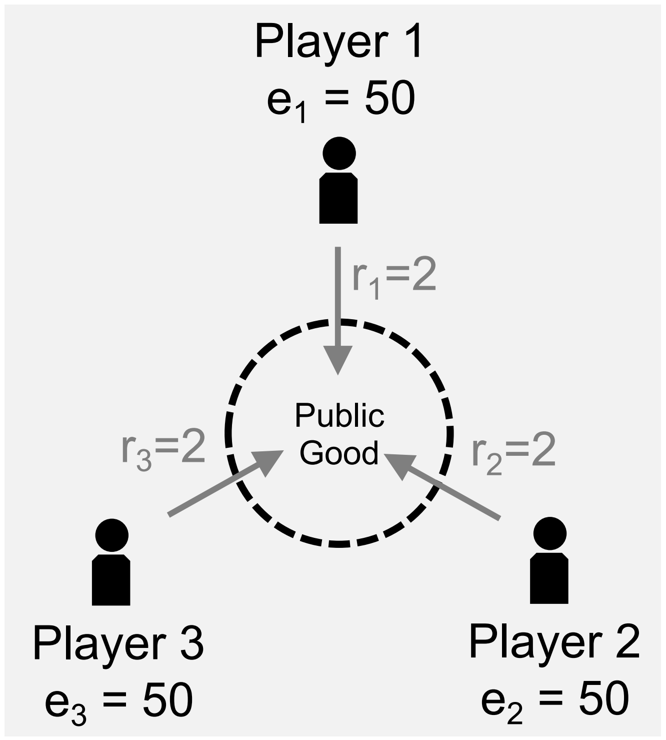

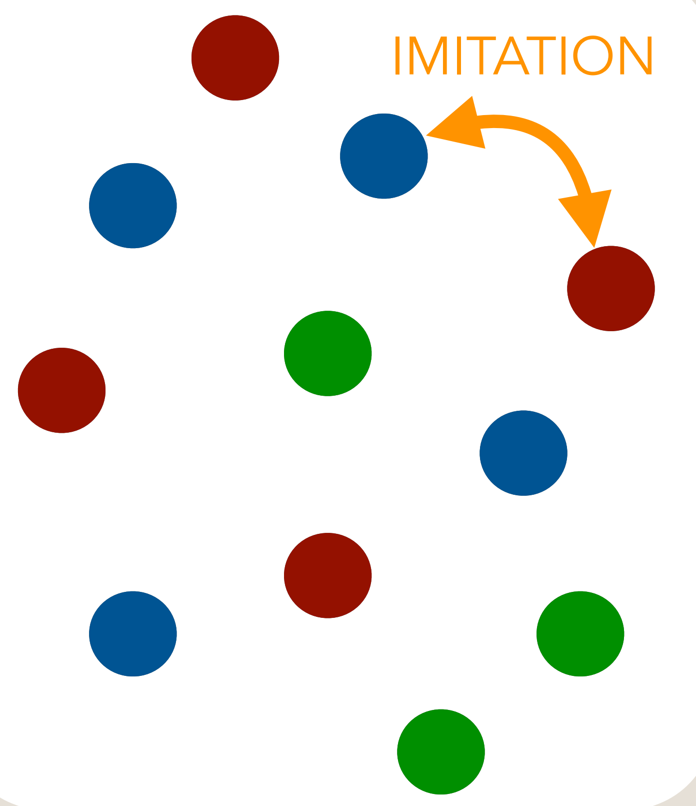

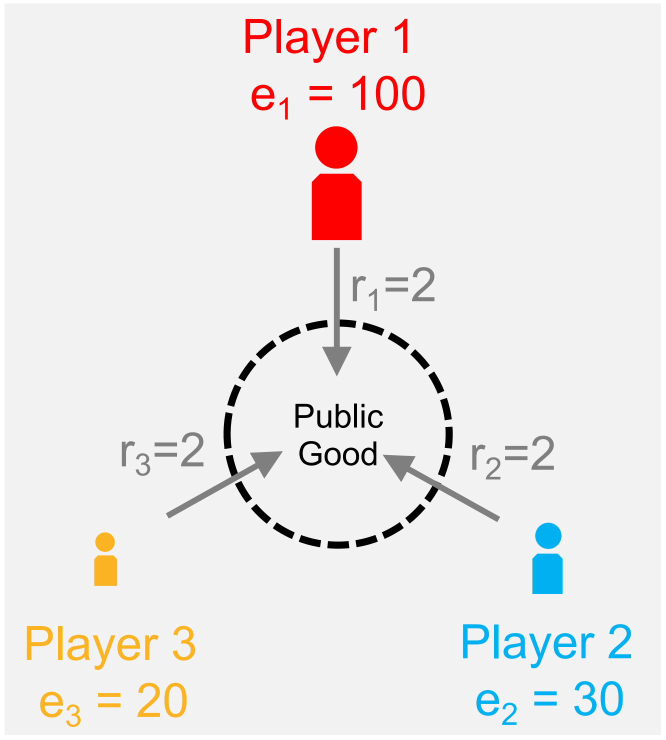

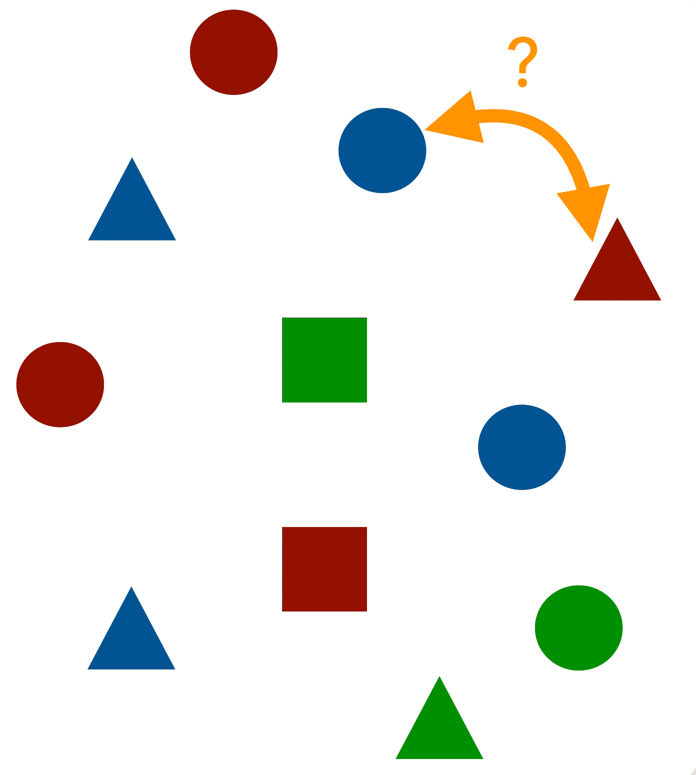

Climate policies under wealth inequality

Vítor V. Vasconcelos[a,b,c], Francisco C. Santos[a,c], Jorge M. Pacheco[a,d,e], and Simon A. Levin[f,g,h,1]

Cooperative interaction of rich and poor can be catalyzed by intermediate climate targets

A letter

Manfred Milinski · Torsten Röhl · Jochem Marotzke

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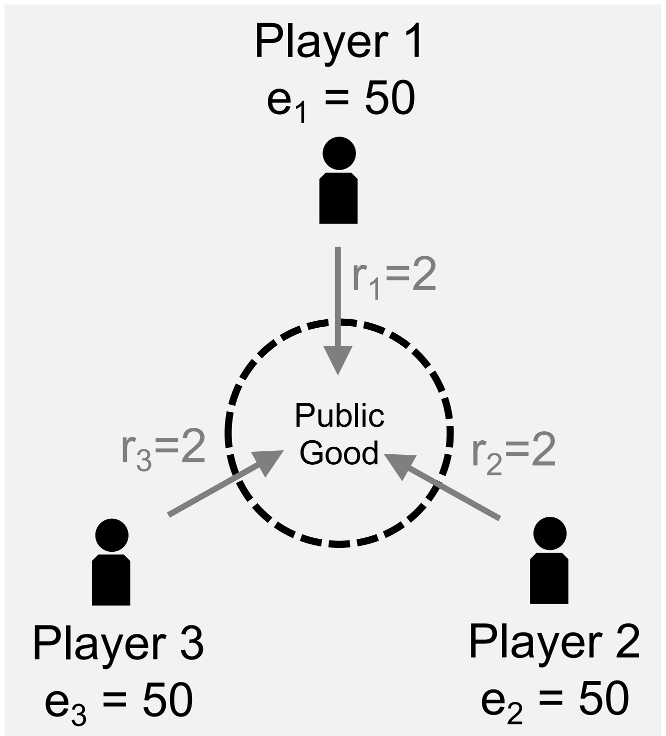

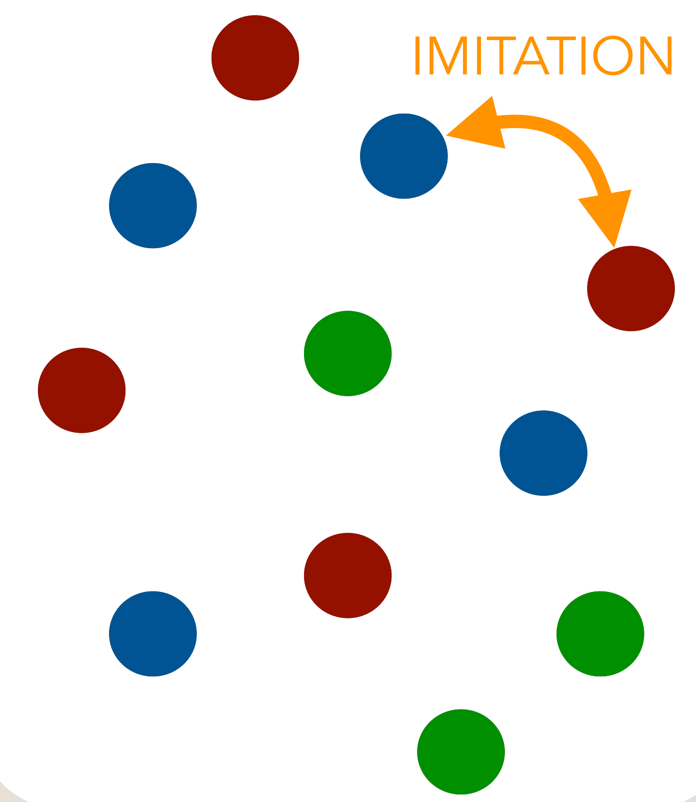

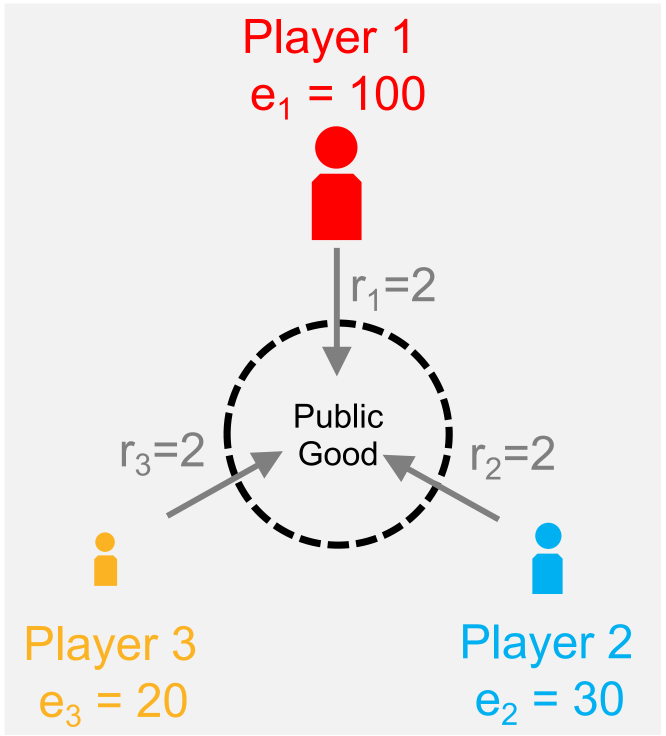

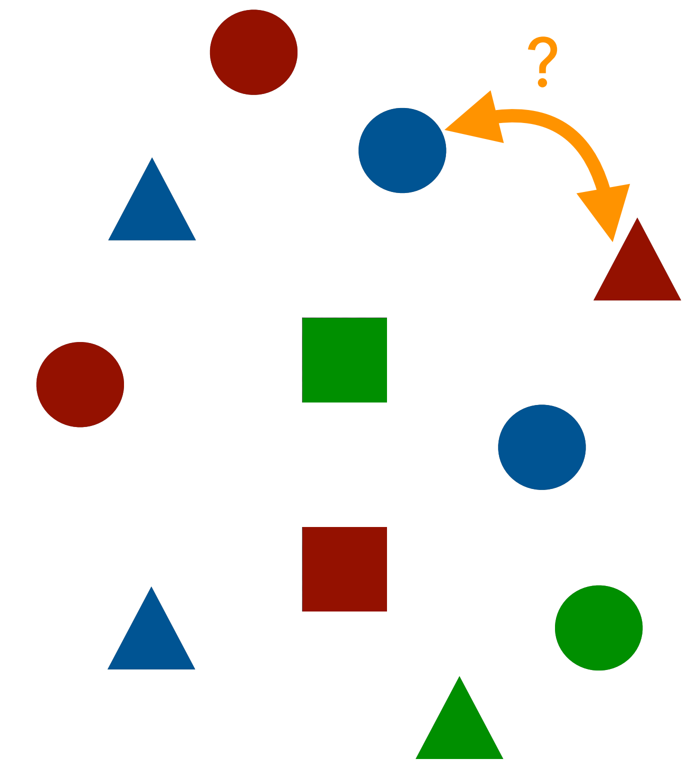

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- There is a group with n individuals who interact repeatedly
- Each round, individual i obtains an endowment e_i
- Individuals independently decide how much to contribute
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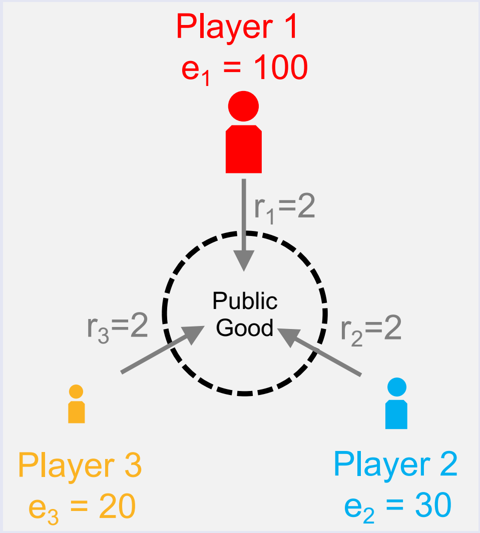

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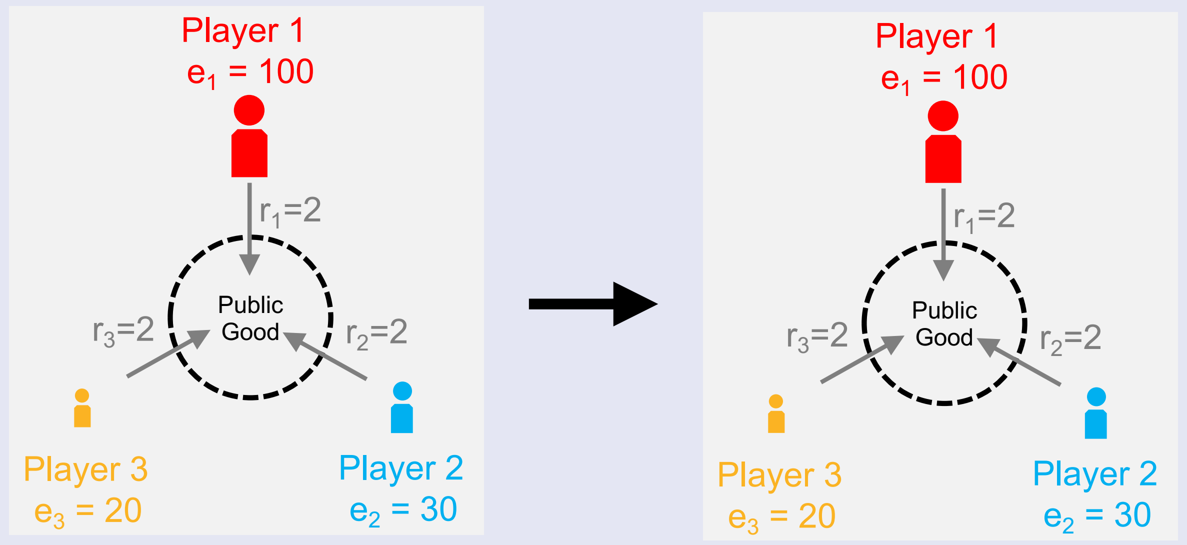

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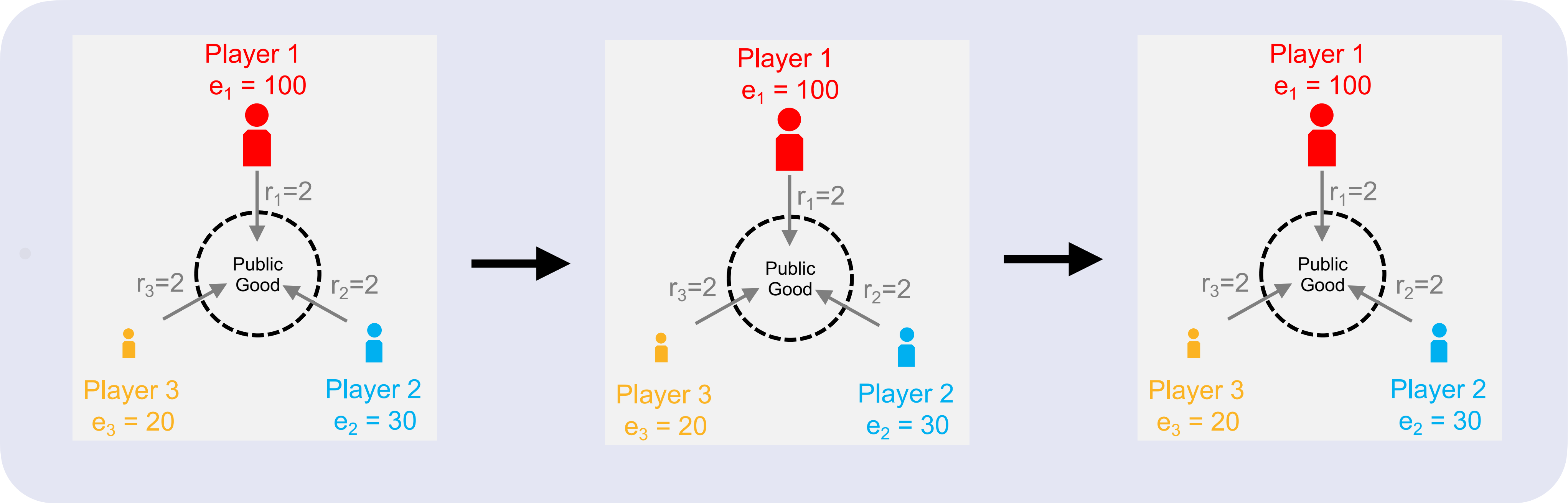

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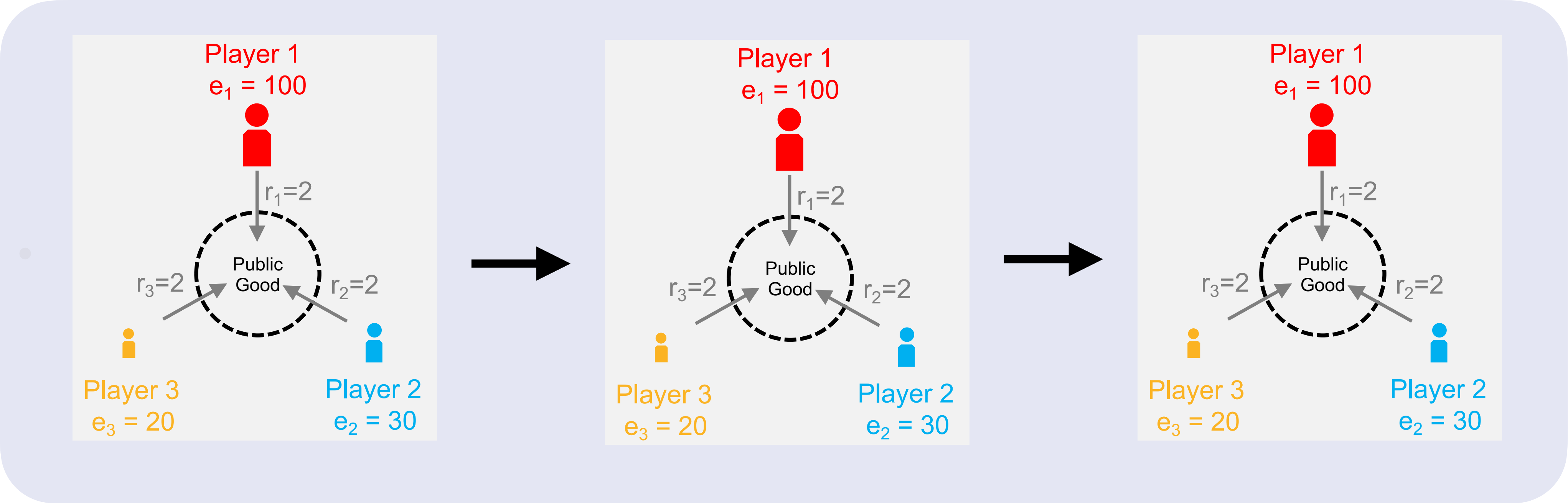

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For given productivities, how should we optimally allocate endowments to maximize cooperation?

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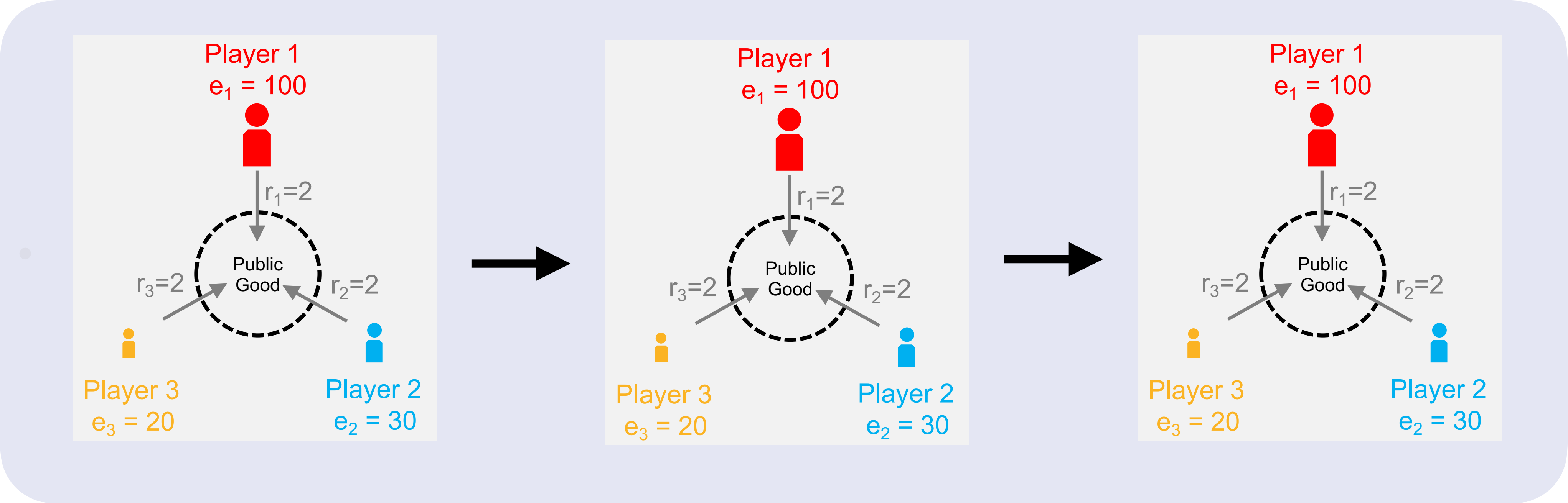

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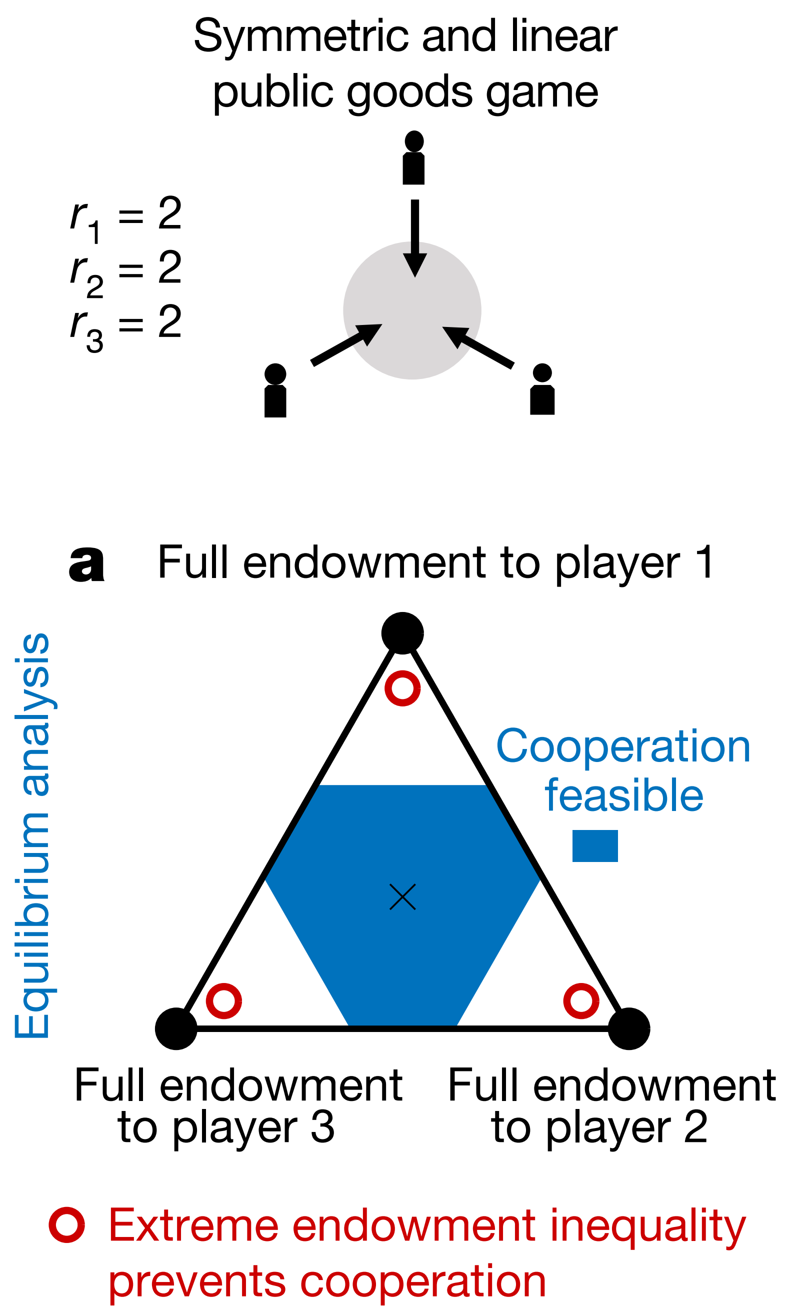

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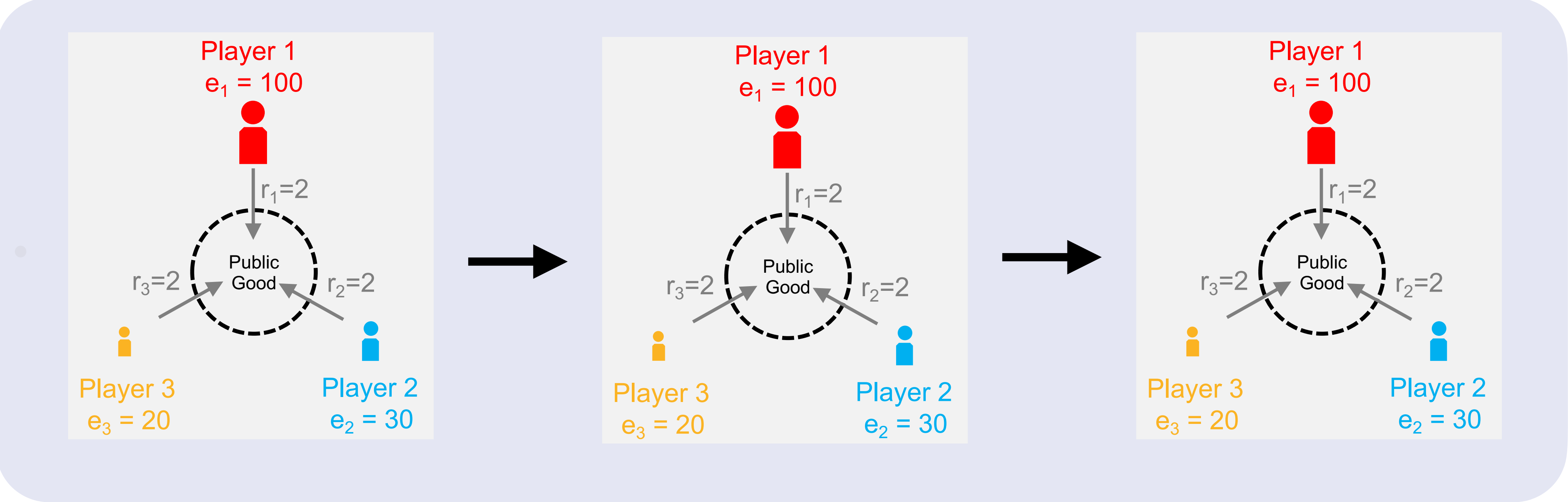

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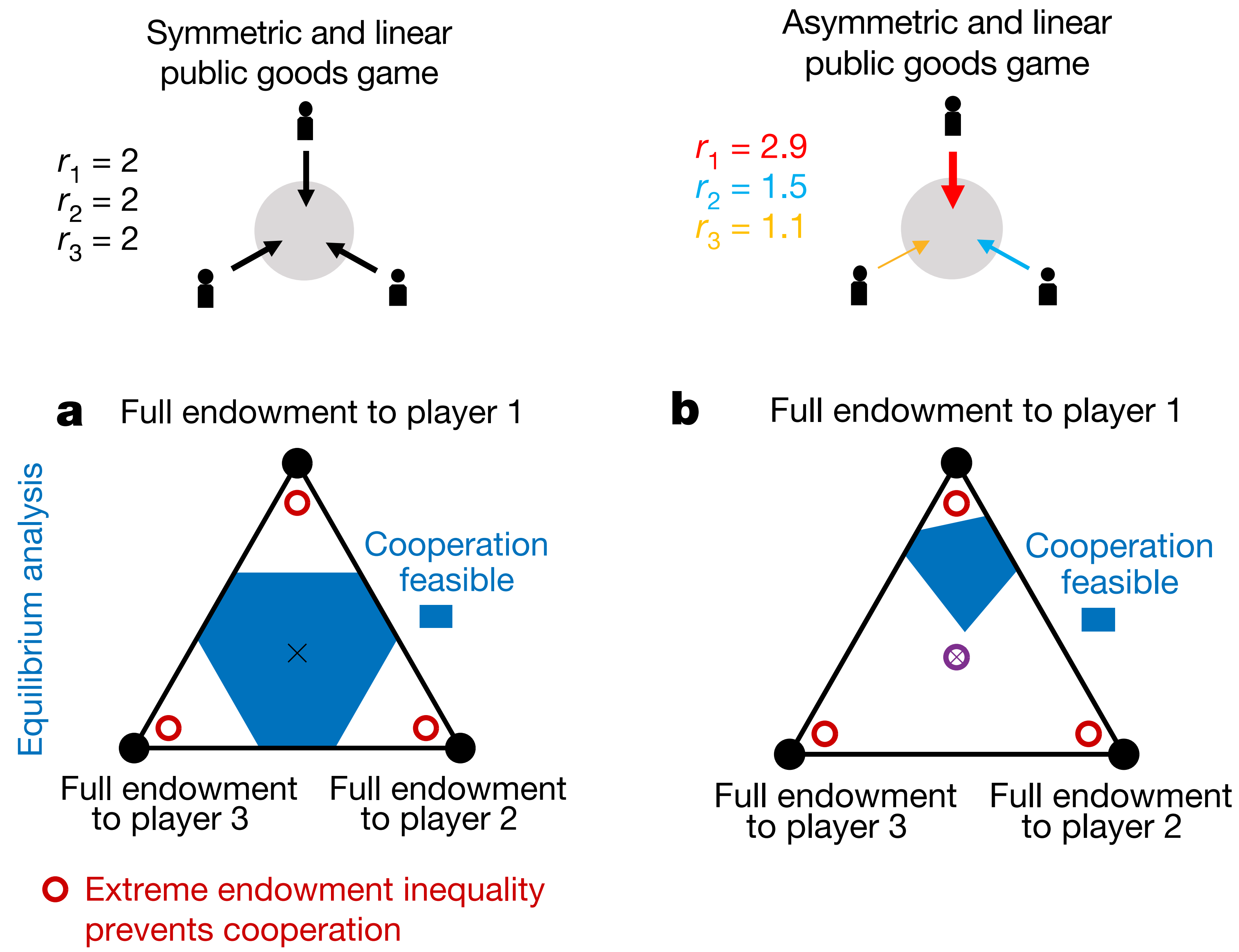

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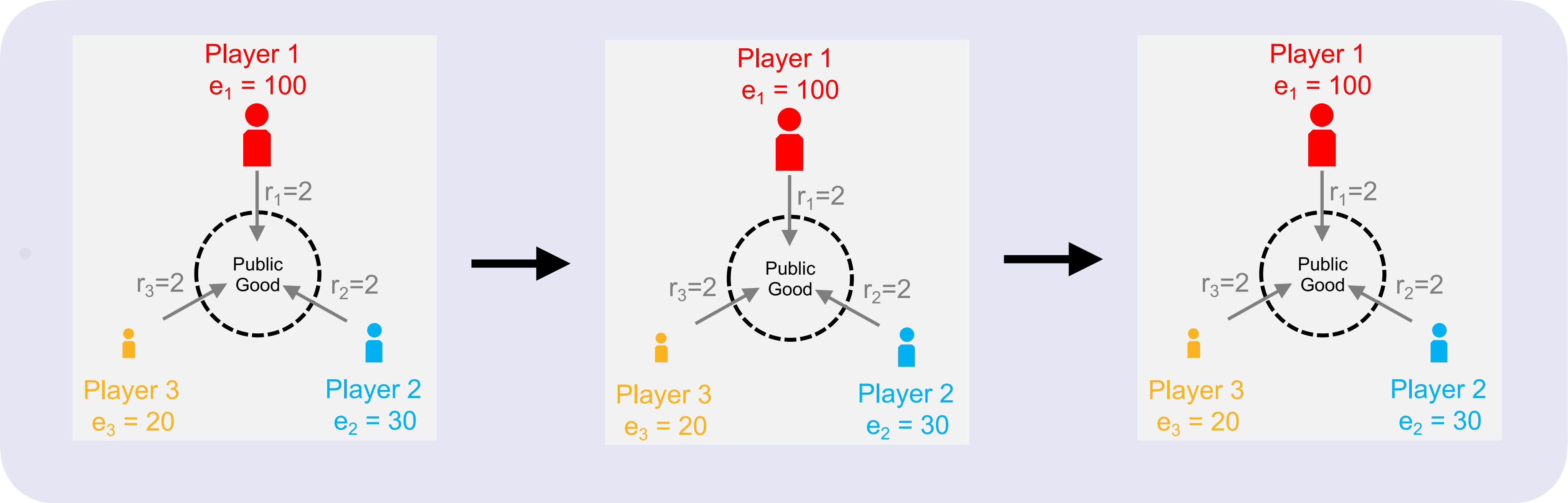

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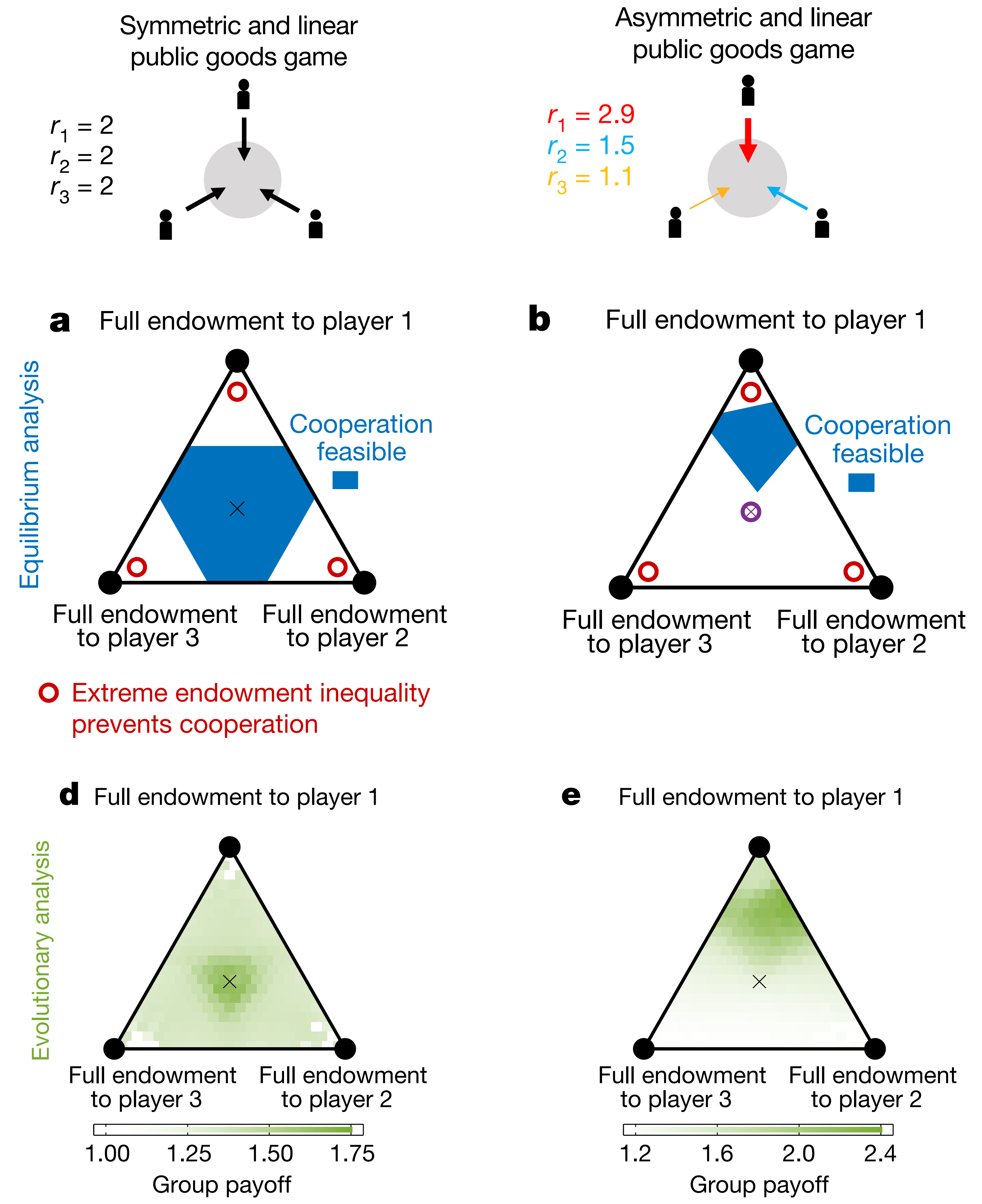

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Remark 4.21. An experiment

- To test these qualitative predictions, we did an experiment
- ~400 participants recruited through Amazon Turk
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Equal endowments — Equal productivities

1 Full equality

	Player 1	Player 2
Endowment	50	50
Productivity	×1.6	×1.6

Equal endowments — Unequal productivities

3 Productivity inequality

	Player 1	Player 2
Endowment	50	50
Productivity	×1.9	×1.3

Unequal endowments — Equal productivities

2 Endowment inequality

	Player 1	Player 2
Endowment	75	25
Productivity	×1.6	×1.6

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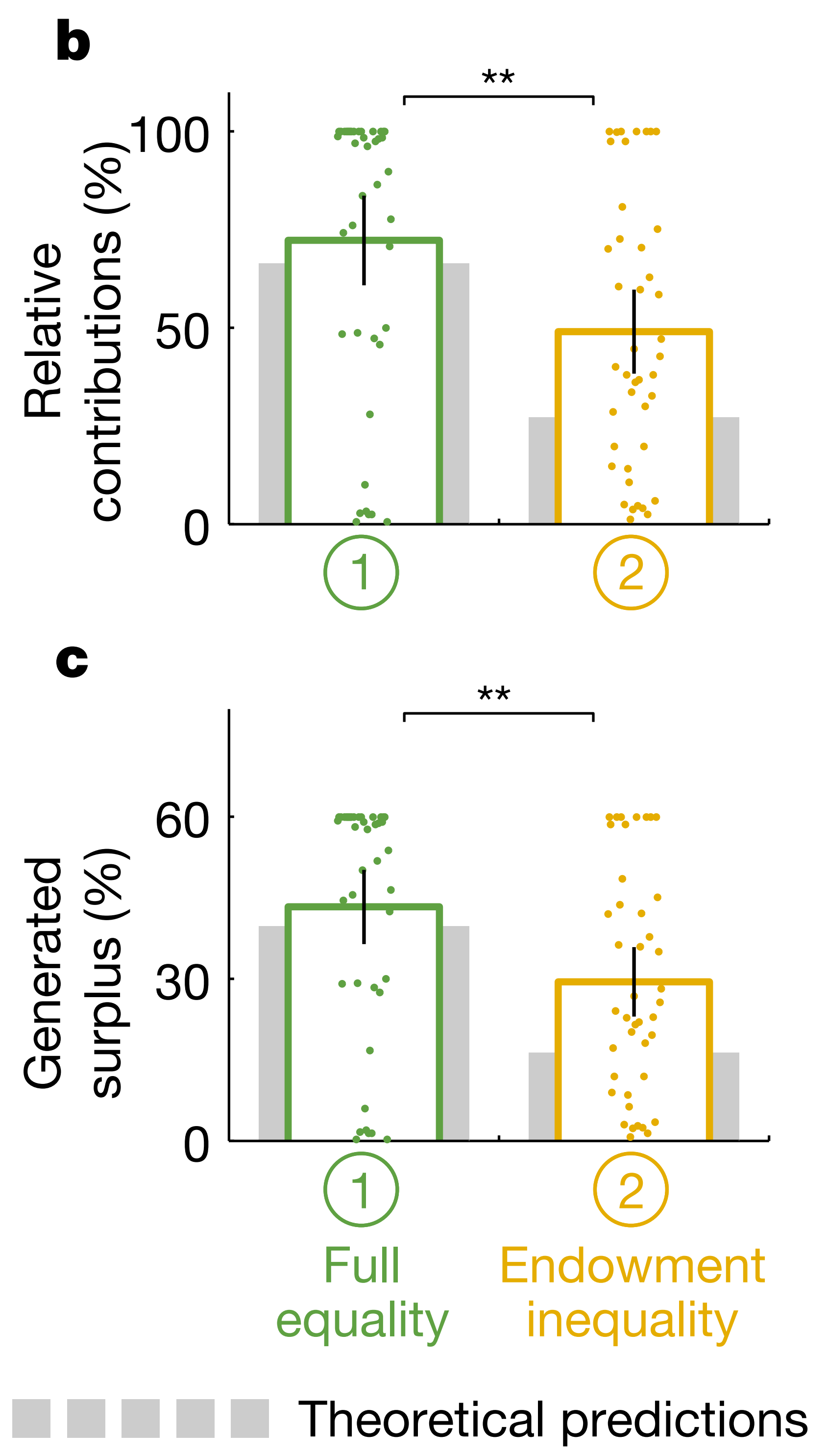

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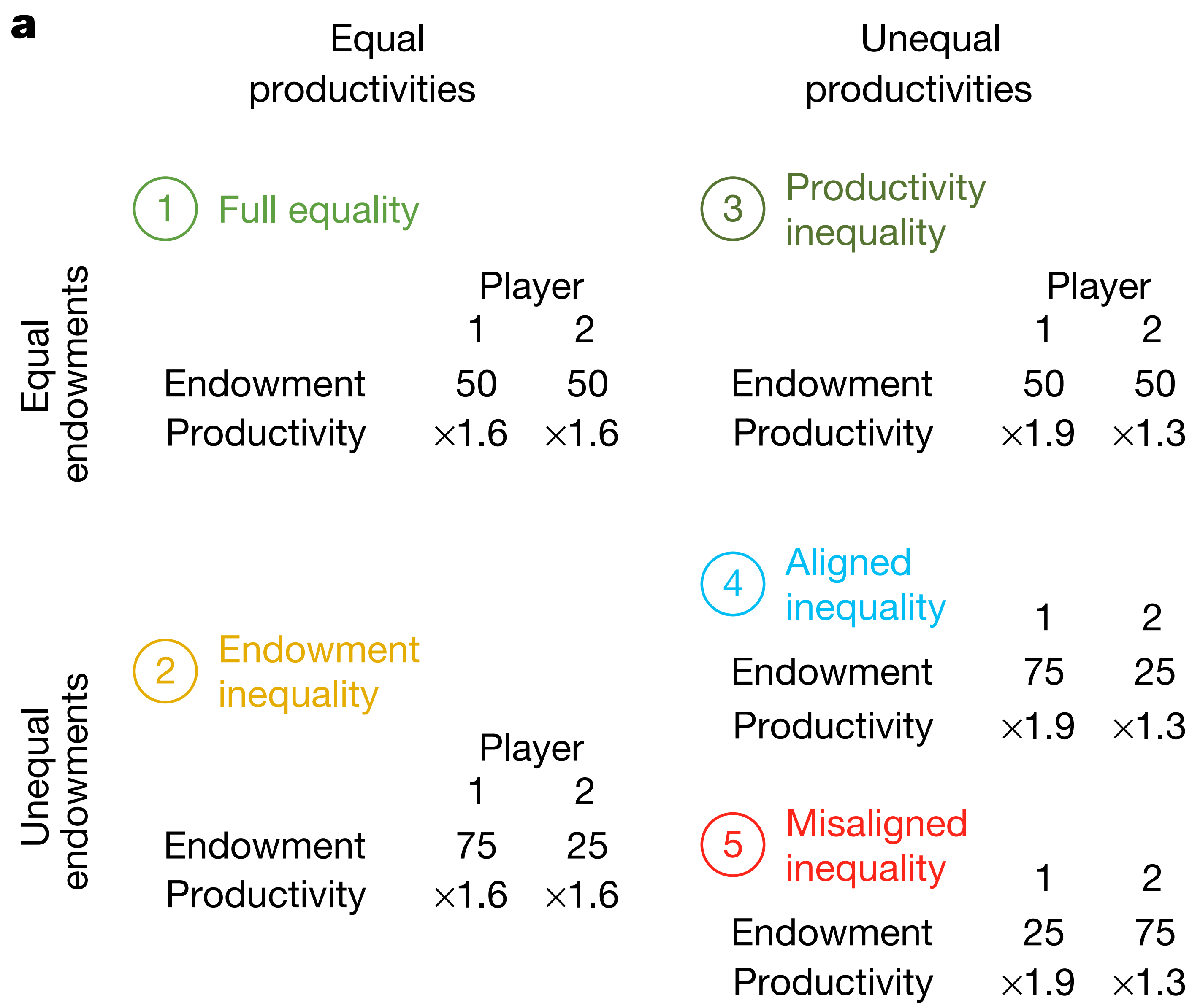

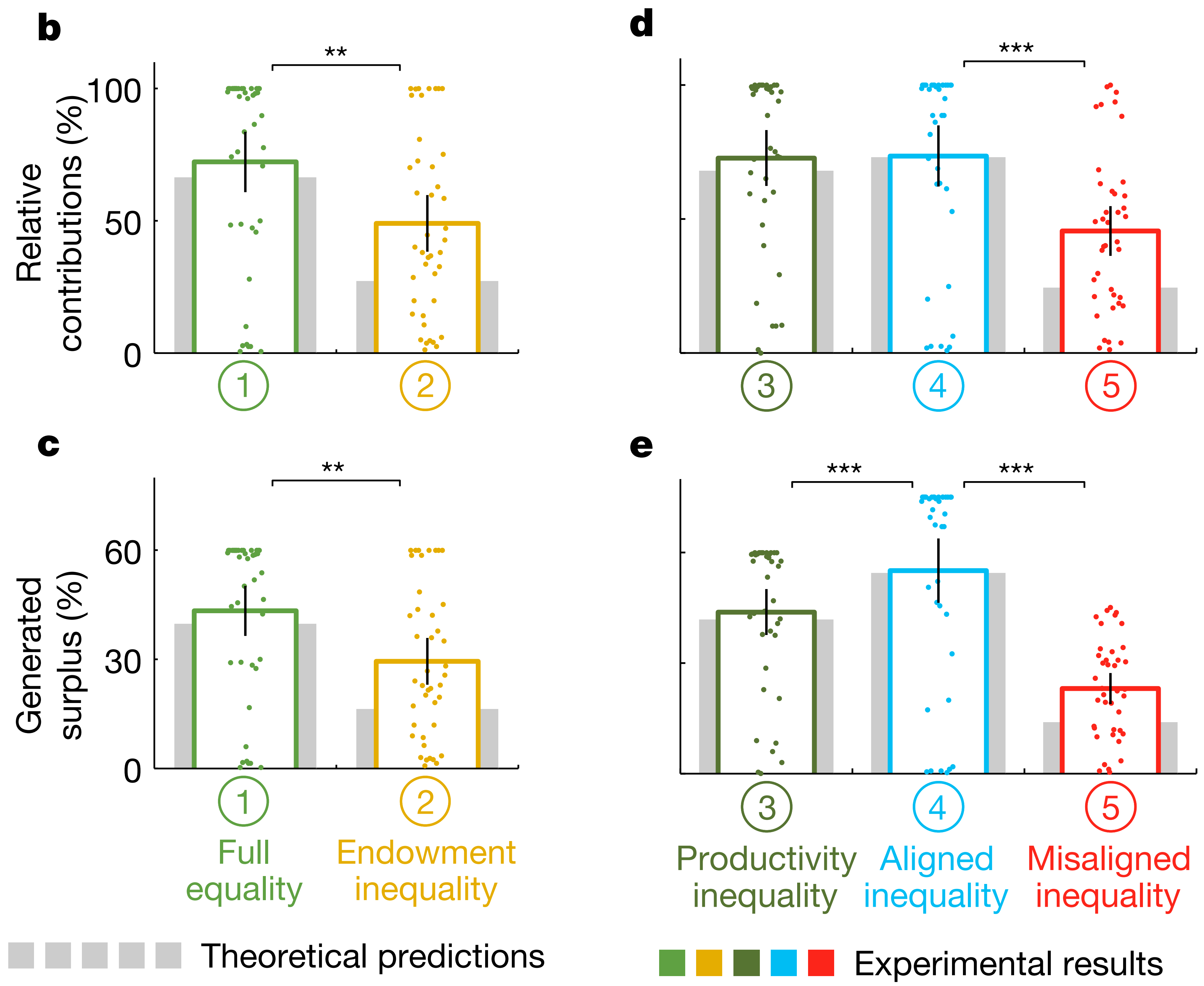

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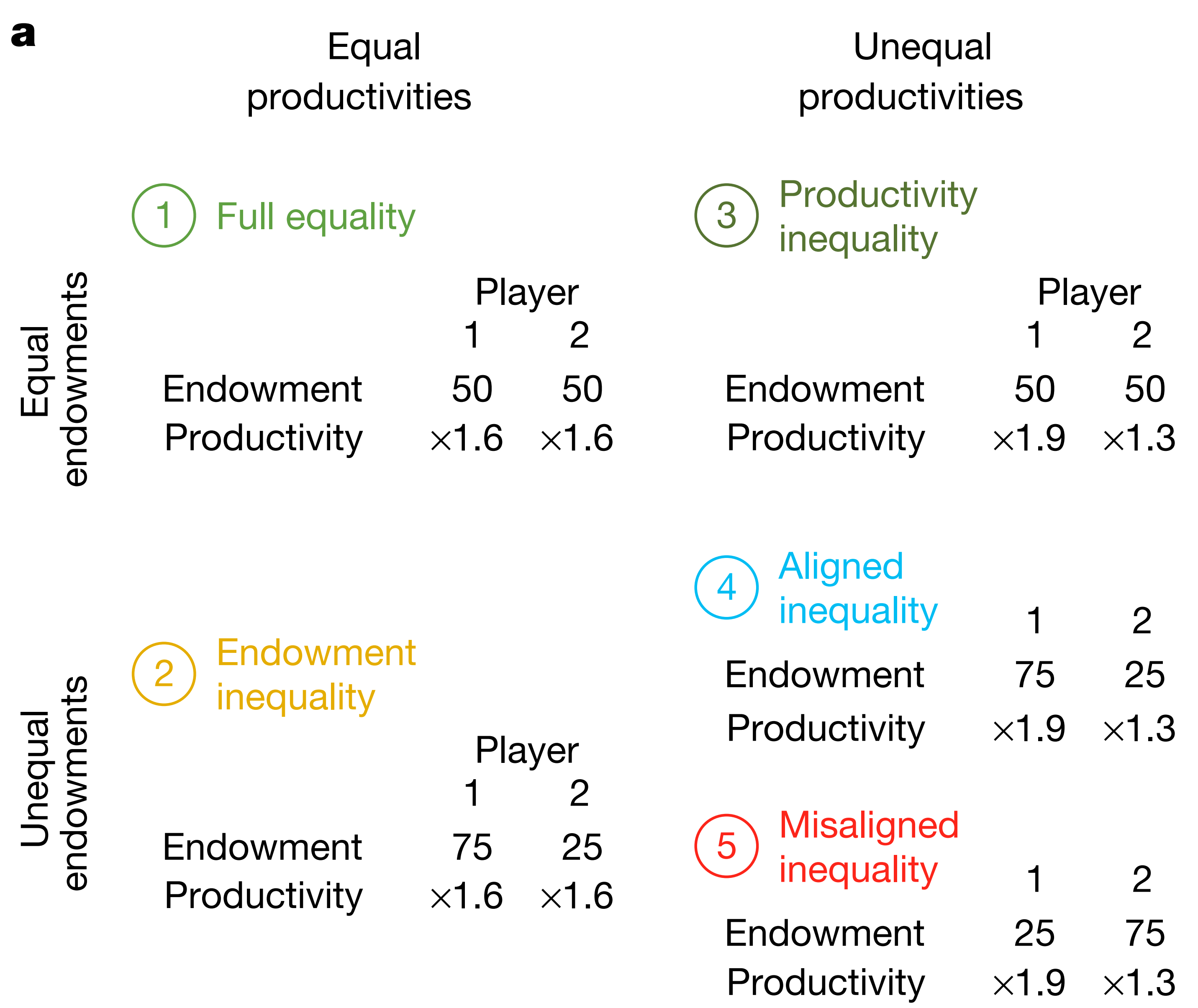

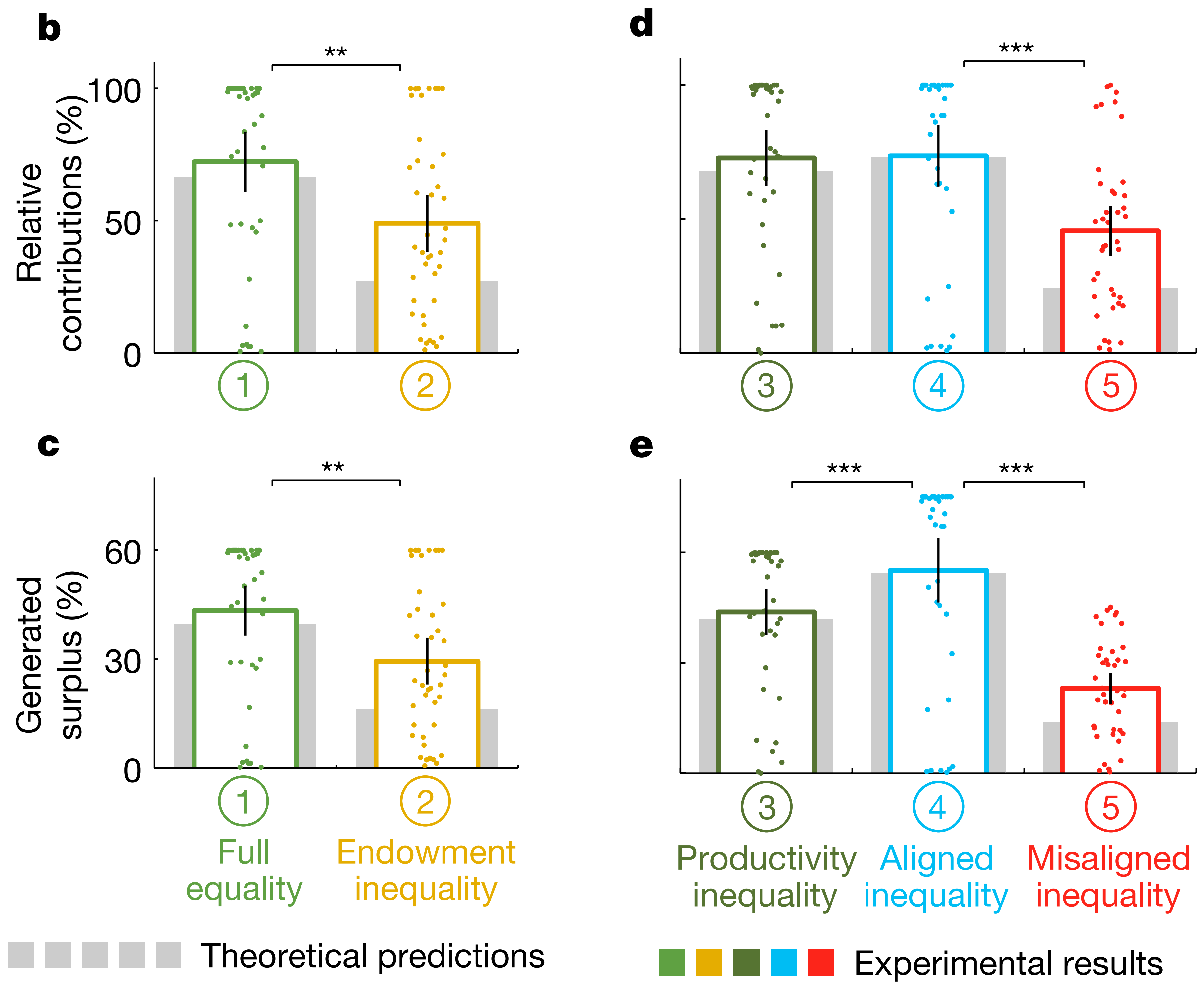

Summary: How to allocate endowments to maximise cooperation?

- When players are equally productive, they should get equal contributions.
- Otherwise, more productive players should get higher endowments (*'aligned inequality'*)

Summary

1. In my lectures, I first provided some introduction to evolutionary game theory (replicator dynamics, Moran process).
2. Then we used to these techniques to further explore the evolution of cooperation (in particular: direct and indirect reciprocity).

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2. Then we used to these techniques to further explore the evolution of cooperation (in particular: direct and indirect reciprocity).
3. Thanks to the organisers, and thanks for being such an engaging audience!

Where to find more information:
http://web.evolbio.mpg.de/social-behaviour/

Collaborators and funding

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Manfred Milinski, MPI for Evolutionary Biology
Laura Schmid, Nature Communications
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IT:U interdisciplinary transformation university austria

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