Should I stay or should I go?

Conditional dissociation in the Evolutionary Emergence of Cooperation

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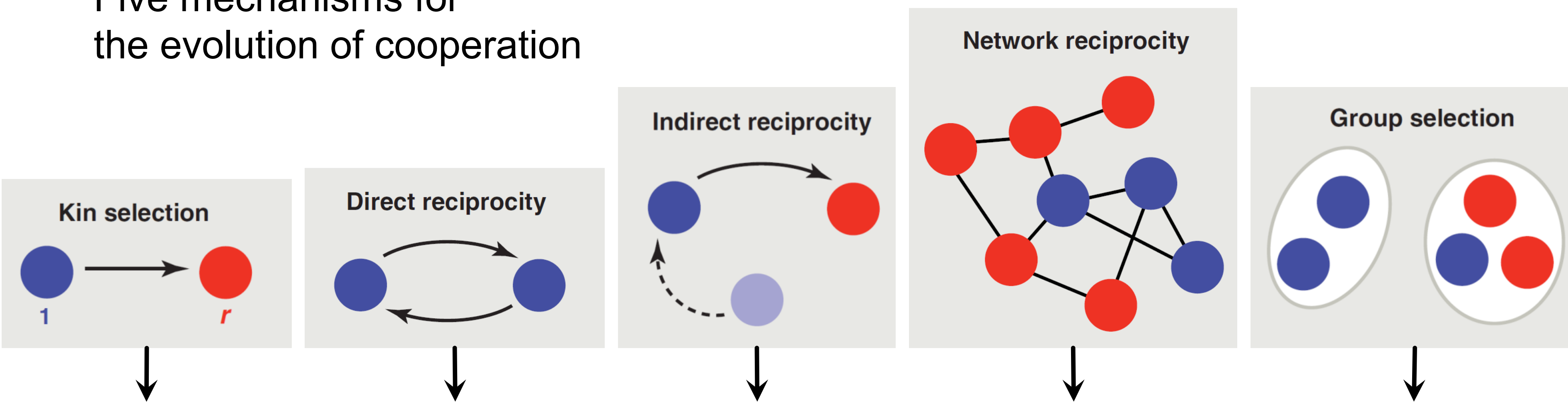
Outline

- Introduction
- The question and the approach
- The model
- Results
- A mean-field approximation
- Conclusions

Introduction

How did cooperative behaviour evolve?

Five mechanisms for
the evolution of cooperation



Kin selection	Direct reciprocity	Indirect reciprocity	Network reciprocity	Group selection
Requires genetic relatedness	Requires recognition and memory	Requires recognition and social monitoring (reputation)	Imposes exogenous structure of interaction	Imposes exogenous structure of interaction and multilevel selection

Cooperators Defectors

Nowak, M. A. (2006) Five rules for the evolution of cooperation. *Science* 314, 1560-1563.

Introduction

Interested in conditional assortment

Situations where individuals have an influence in determining with whom they interact (or not)

- *Pre-interaction* partner selection (or refusal)
  - Requires advanced cognitive abilities.
  - E.g.: Indirect reciprocity (reputation), external signals or tags...
- *Post-interaction* partner-refusal
  - It does not require memory or the ability to anticipate the behaviour of new partners.
  - It only requires the capacity to escape an unpleasant situation.

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The question

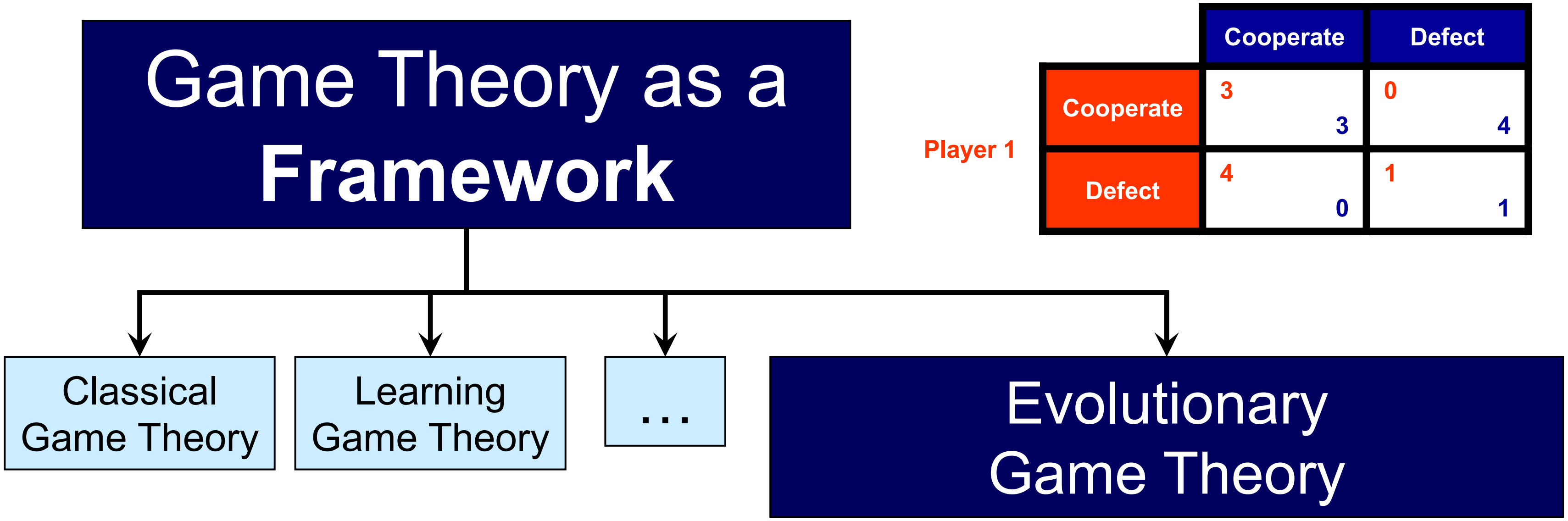
- Can a simple mechanism of post-interaction partner refusal (i.e. conditional dissociation) explain the evolutionary emergence of cooperation among unrelated individuals?

The approach

Game Theory as a Framework

		Player 2	
		Cooperate	**Defect**
Player 1	**Cooperate**	3 / 3	0 / 4
	Defect	4 / 0	1 / 1

The approach



		Player 2	
		Cooperate	Defect
Player 1	Cooperate	3, 3	0, 4
	Defect	4, 0	1, 1

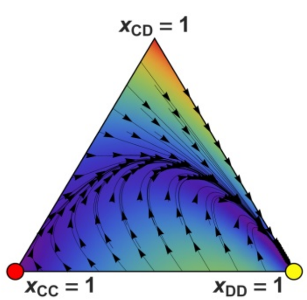
The approach

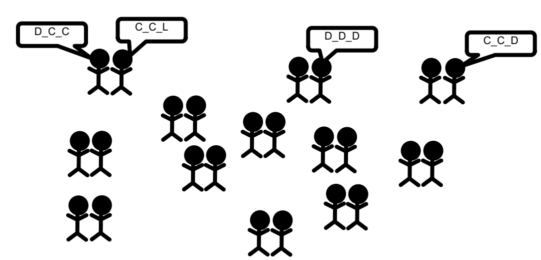
Player 2

Player 1		Cooperate	Defect
	Cooperate	3, 3	0, 4
	Defect	4, 0	1, 1

Game Theory as a **Framework**

- Classical Game Theory
- Learning Game Theory
- …
- Evolutionary Game Theory
  - Mainstream Evolutionary Game Theory
  - Explicit modelling of actual populations



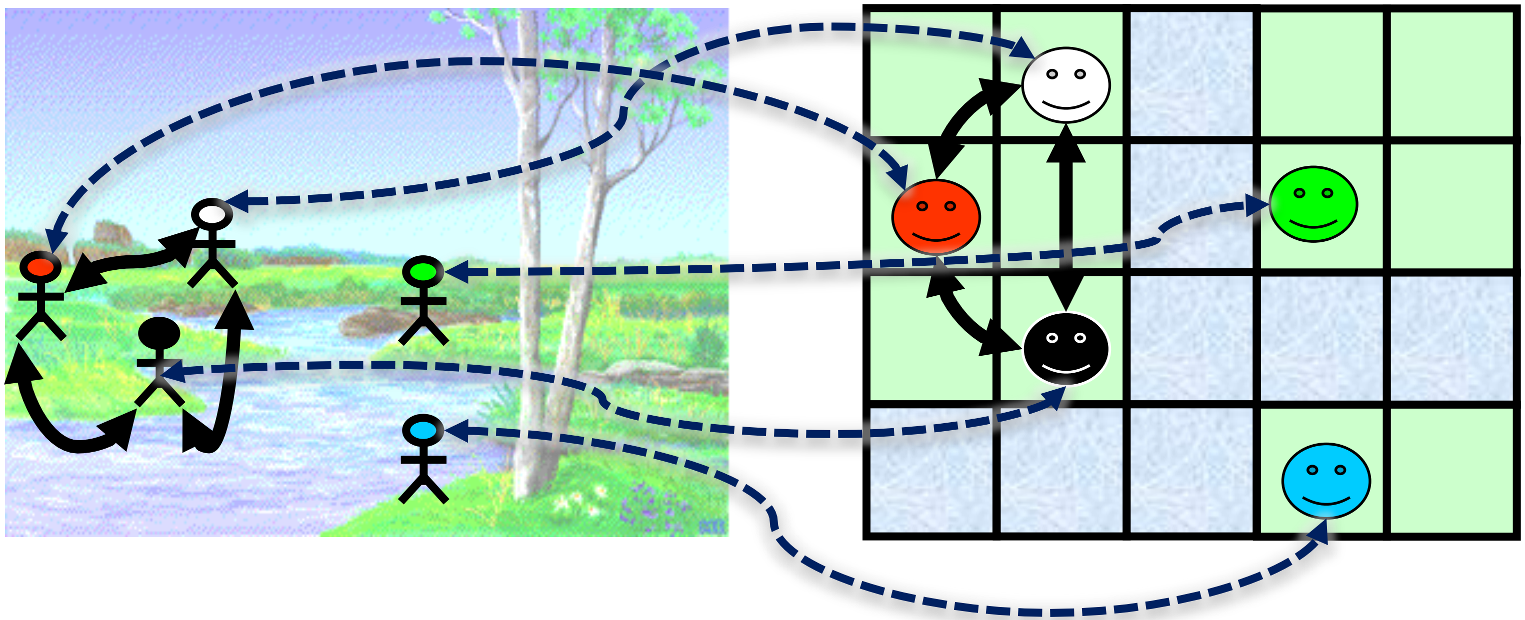


The approach

- Agent-based modelling:

Target (real) system

Agent-based model

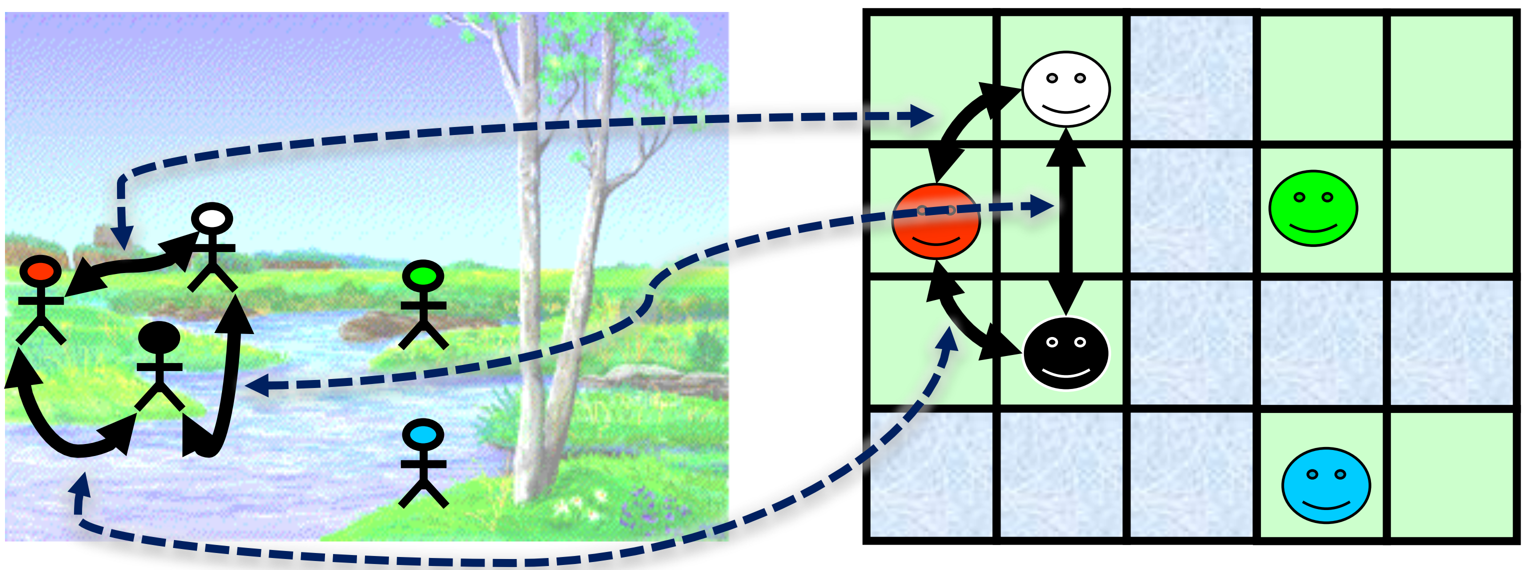


Entities ←--------→ Agents

The approach

- Agent-based modelling:

Target (real) system **Agent-based model**



Interactions among entities ⟷ Interactions among agents

The approach

- Selection of strategies:

  All individuals in the population share a common capability to gather information and to condition their actions on that information, and then allow for *every* possible strategy within such a uniform setup.

- Beyond the identification of “winning” strategies.

  Also concerned with the issue of whether some well-defined pattern of aggregate behaviour eventually emerges.
  (Even under perpetual turnover in strategy choice)

- In short, we strive to understand what factors determine the emergence and stability of cooperative behaviour.

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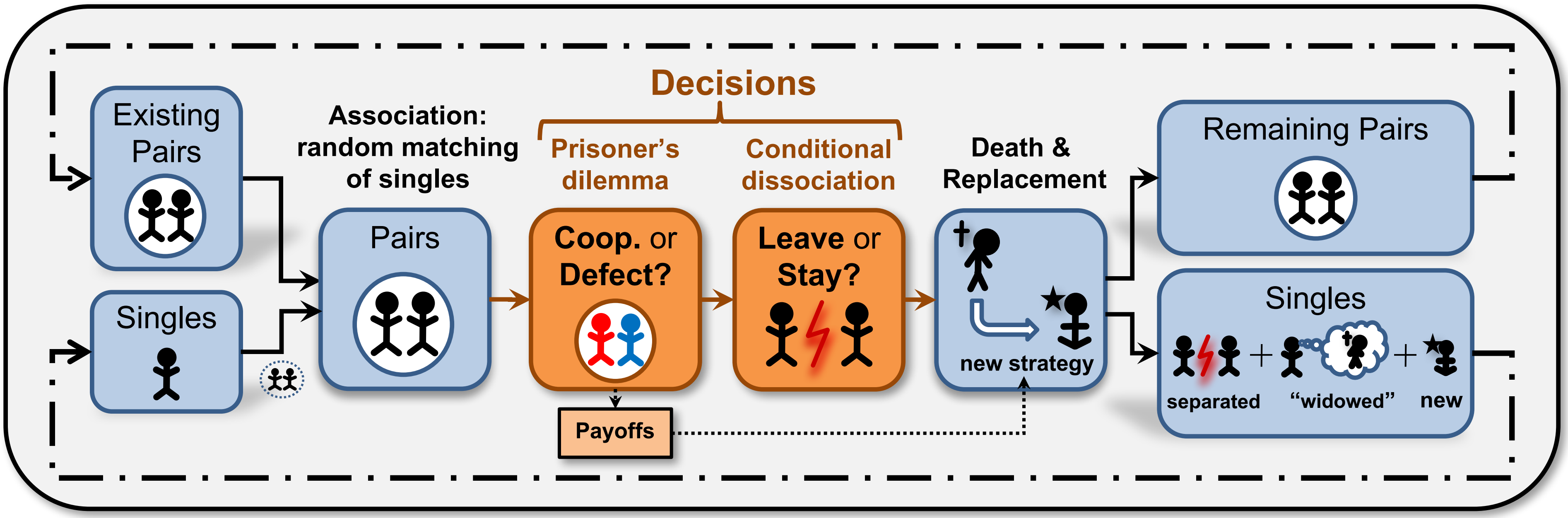
The game (Prisoner's Dilemma)

The Prisoner's Dilemma: Payoffs

Player 2

		Cooperate	Defect
Player 1	Cooperate	3, 3	0, 4
	Defect	4, 0	1, 1

The timeline



Sequence of events within each time period

The strategies: X1_X2_X3

X1

{C, D}

↑

Action with a new partner

C: Cooperate

D: Defect

X2

{C, D, L}

↑

Action to take if one's current partner cooperated

C: **Stay** with partner and **Cooperate** in the next time-step.

D: **Stay** with partner and **Defect** in the next time-step.

L : **Leave**.

X3

{C, D, L}

↑

Action to take if one's current partner defected

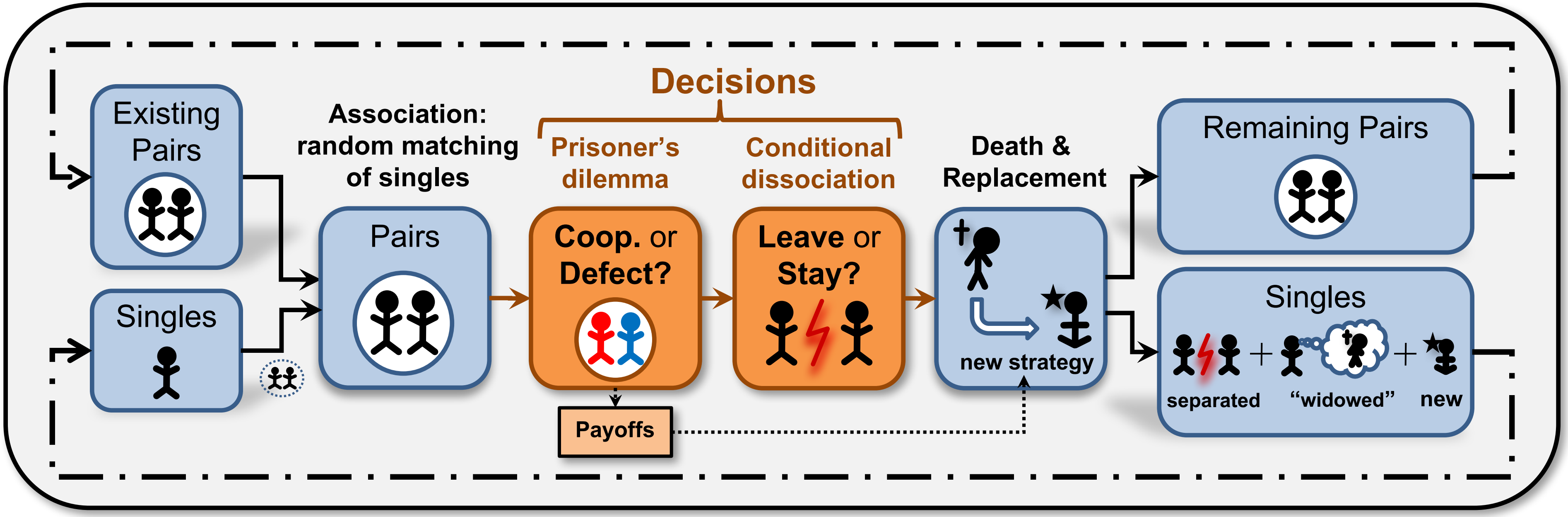
C: **Stay** with partner and **Cooperate** in the next time-step.

D: **Stay** with partner and **Defect** in the next time-step.

L : **Leave**.

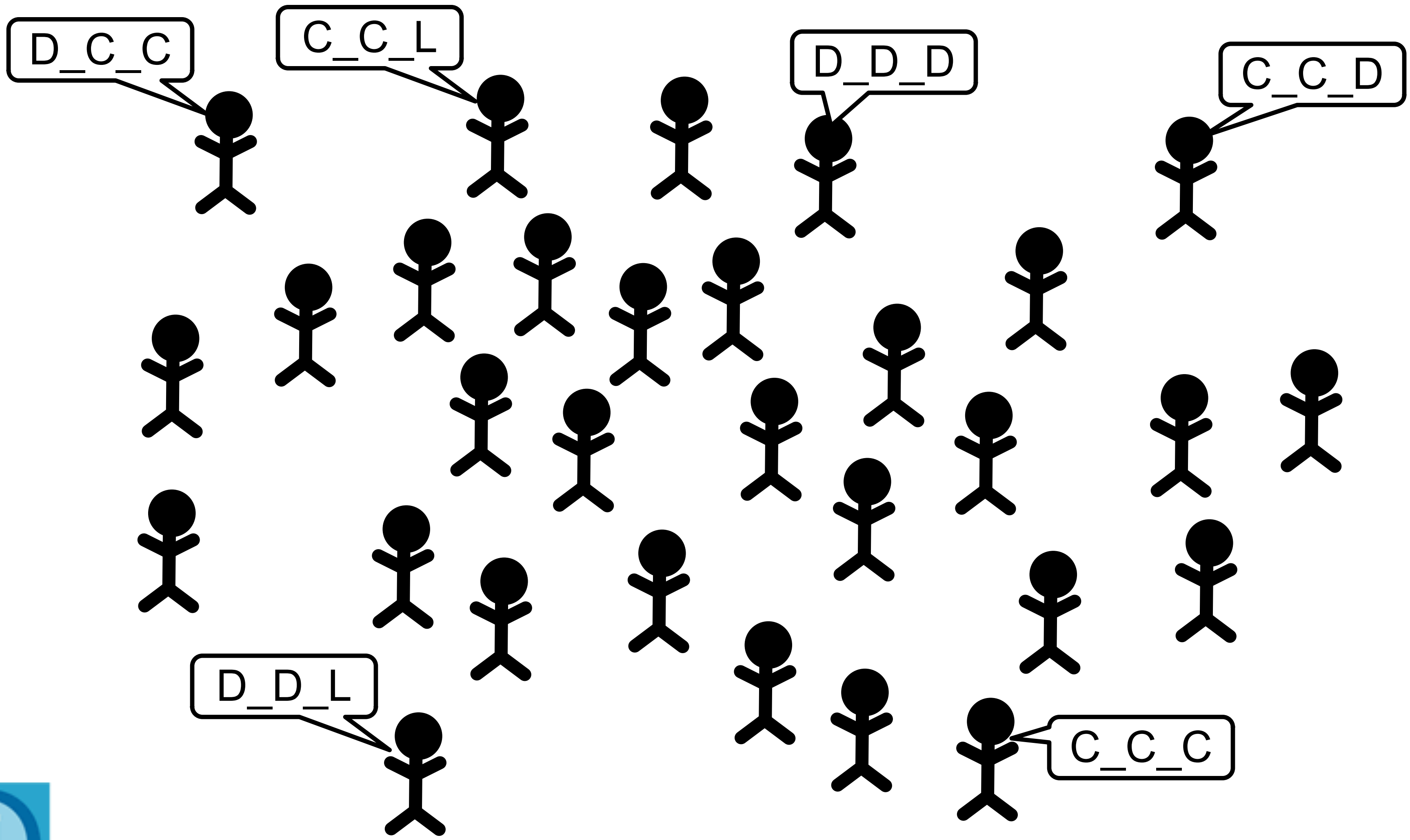
Cooperate and leave after a partner's defection: C_C_L

The timeline

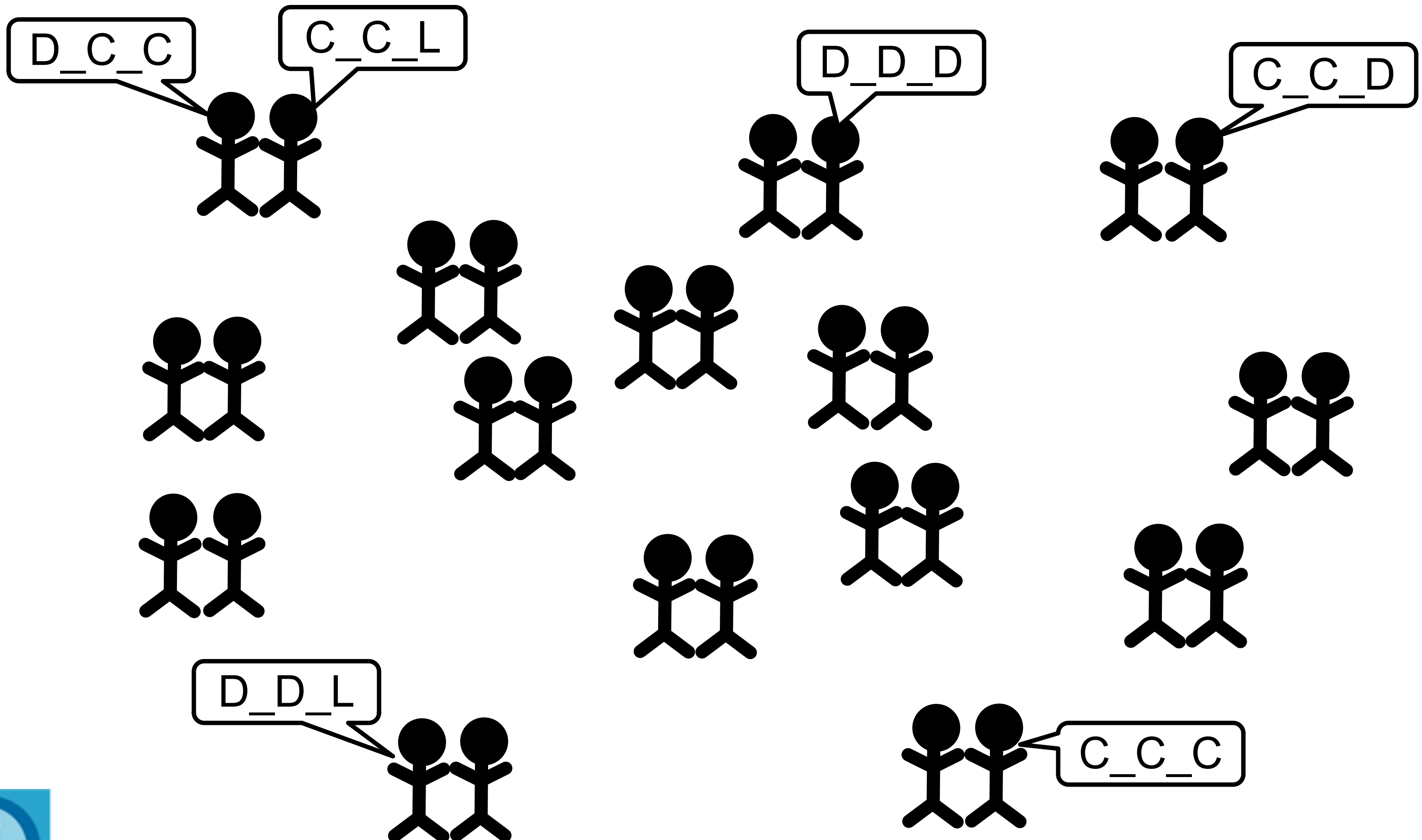


Sequence of events within each time period

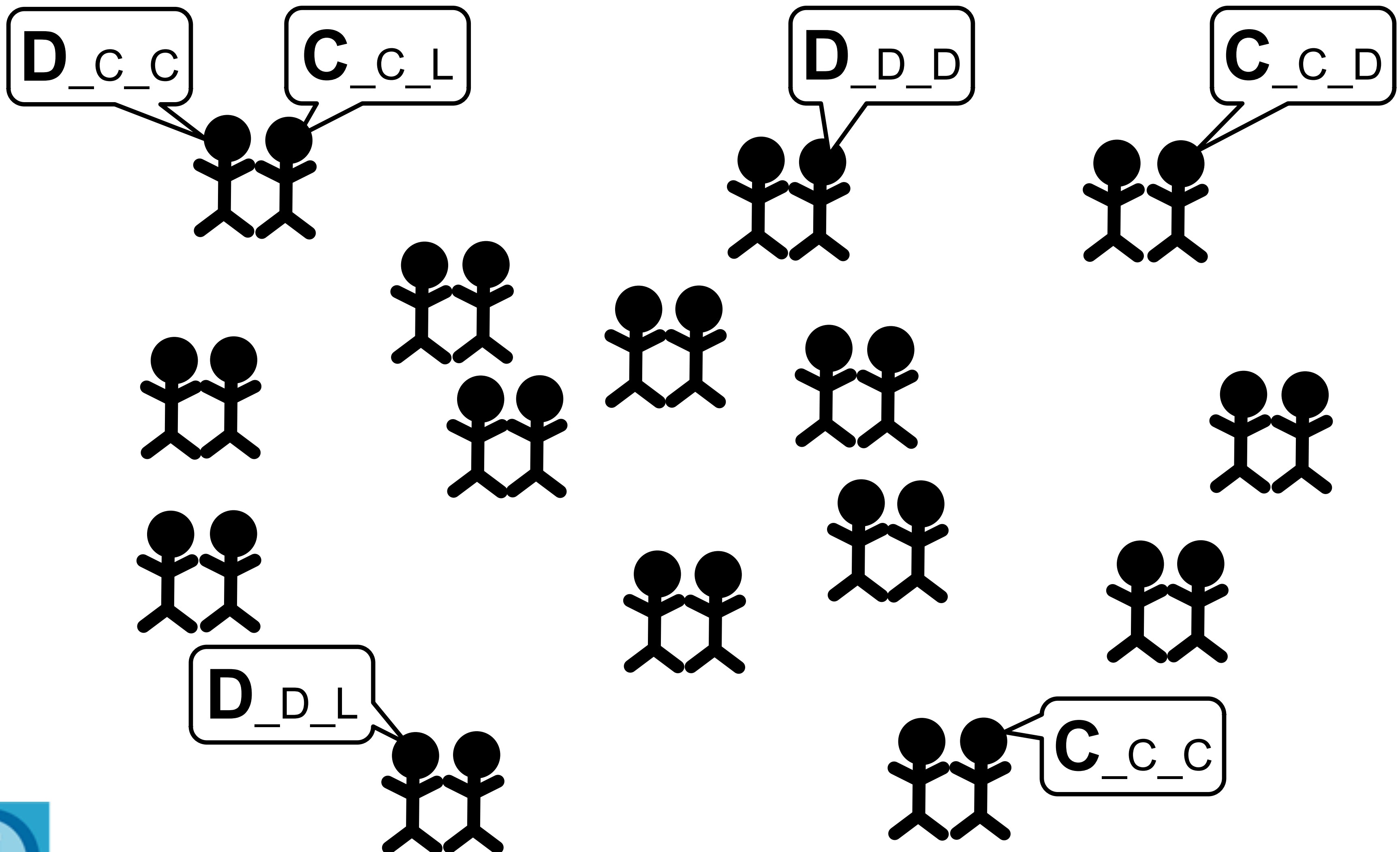
The initial population



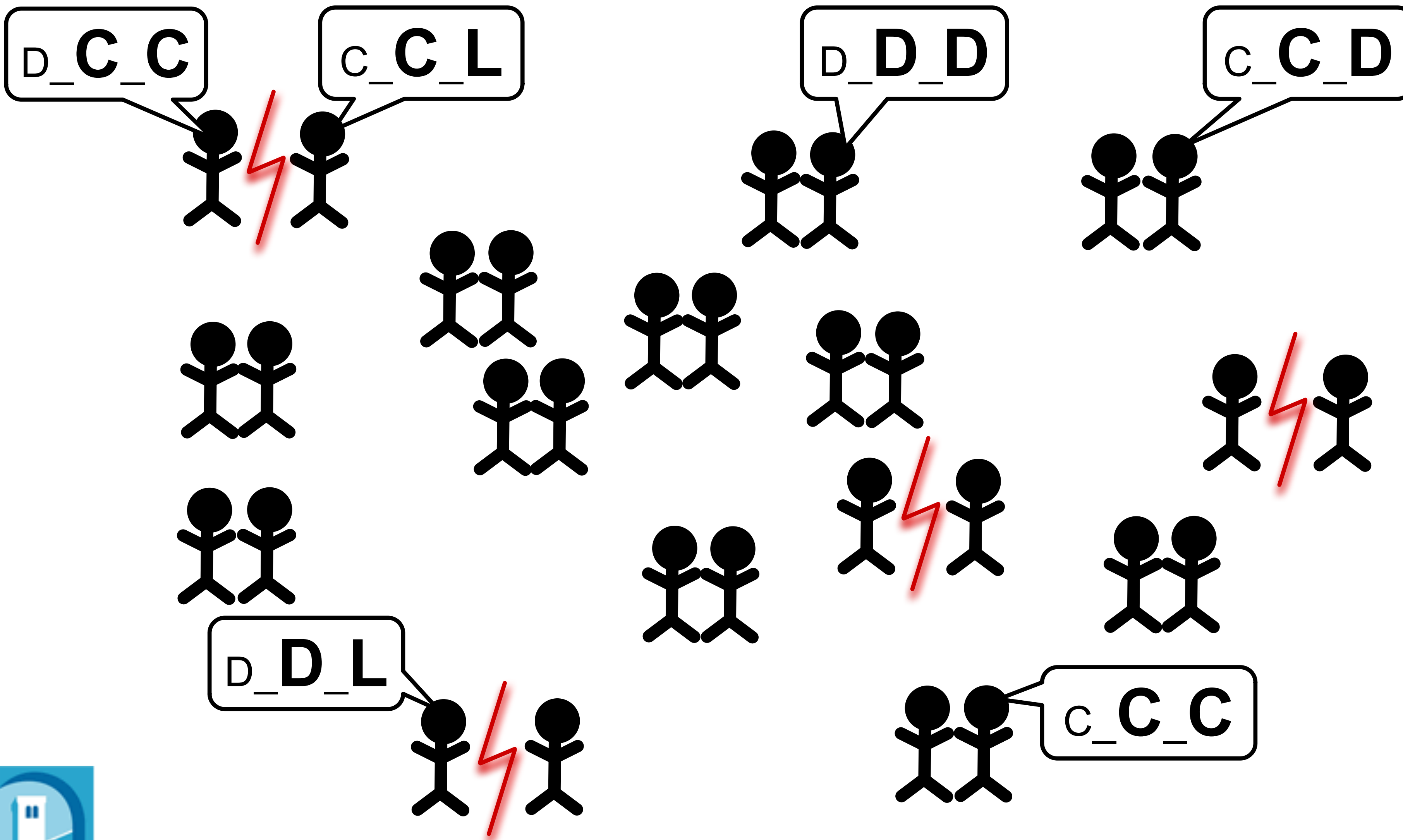
The random pairing of singles



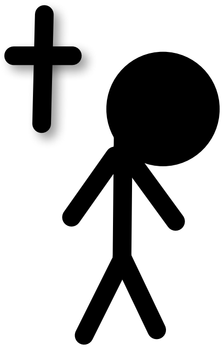
The Prisoner's Dilemma game



Should I stay or should I go?



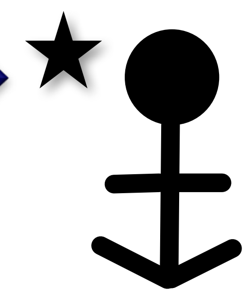
Death and Replacement



Individuals randomly die, an event that occurs independently for each individual with probability *p* in each time period.

Hence, **the lifespan of an individual is geometrically distributed with mean-value *expLife*** = 1/*p*.

Each dead individual is immediately replaced by a new entrant



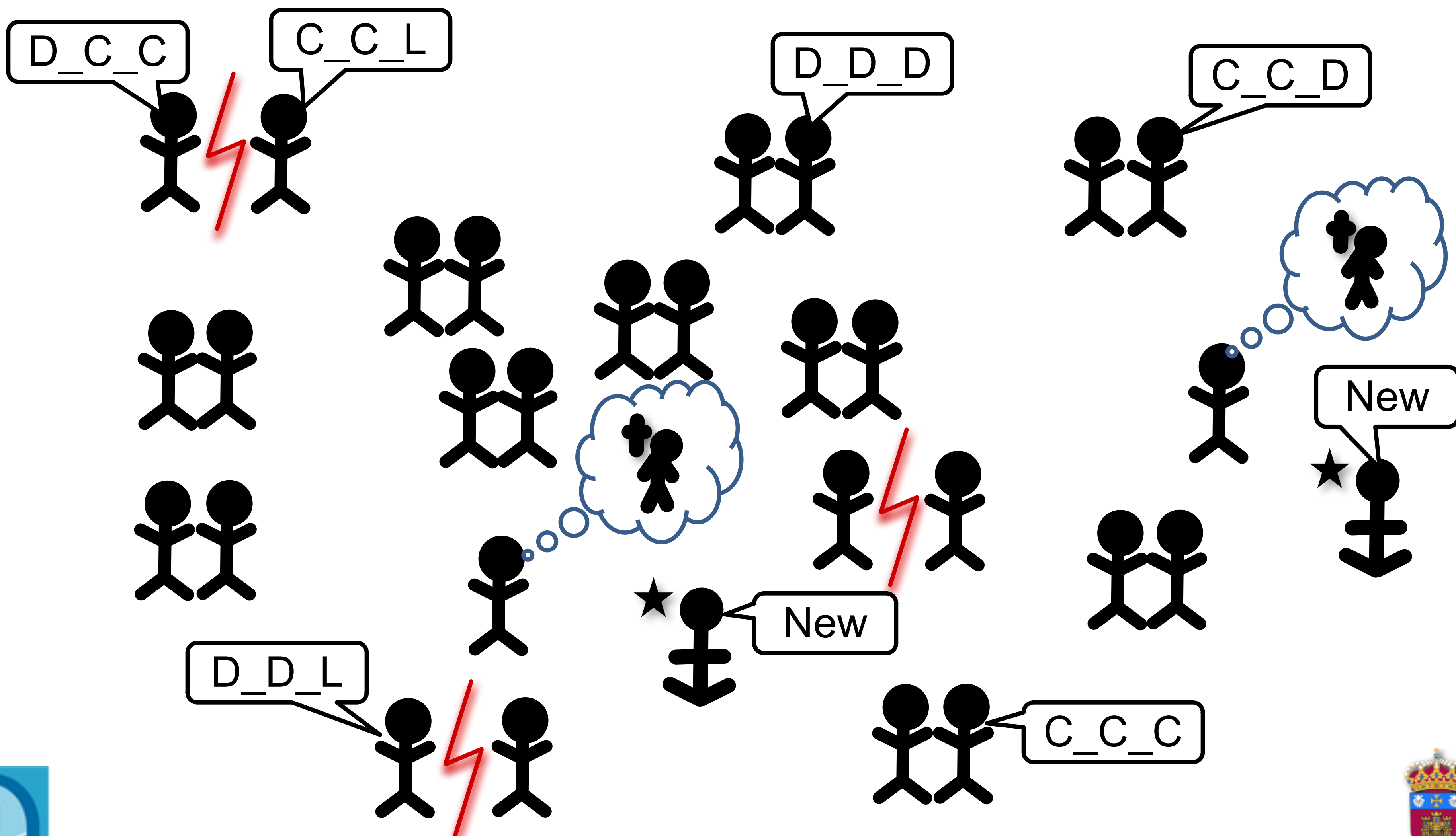
new strategy

Reproduction is proportional to payoffs and population size is kept constant.

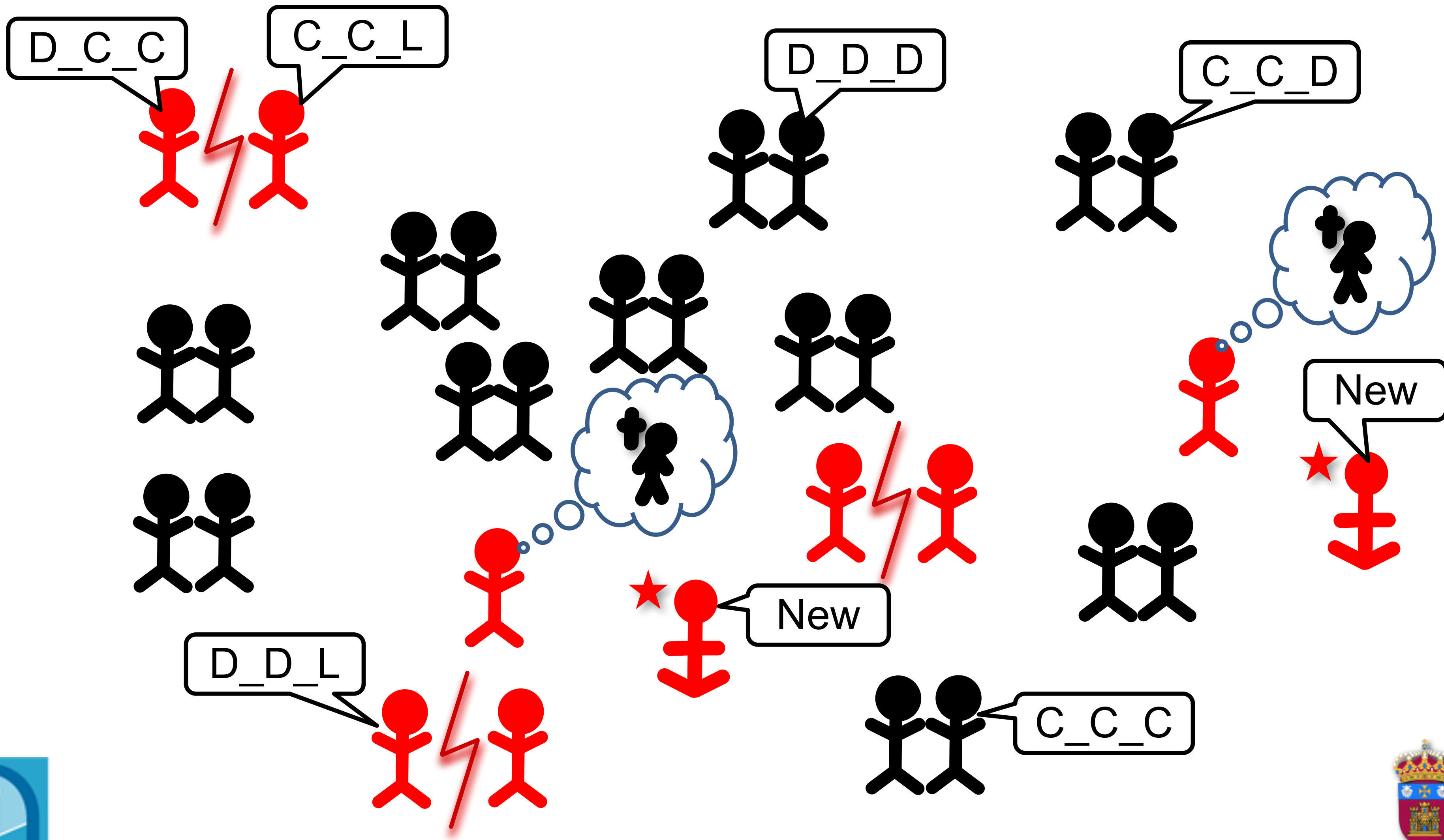
(The probability of adopting a certain strategy is proportional to its aggregate payoff).

Random mutations occur with probability ***μ***.

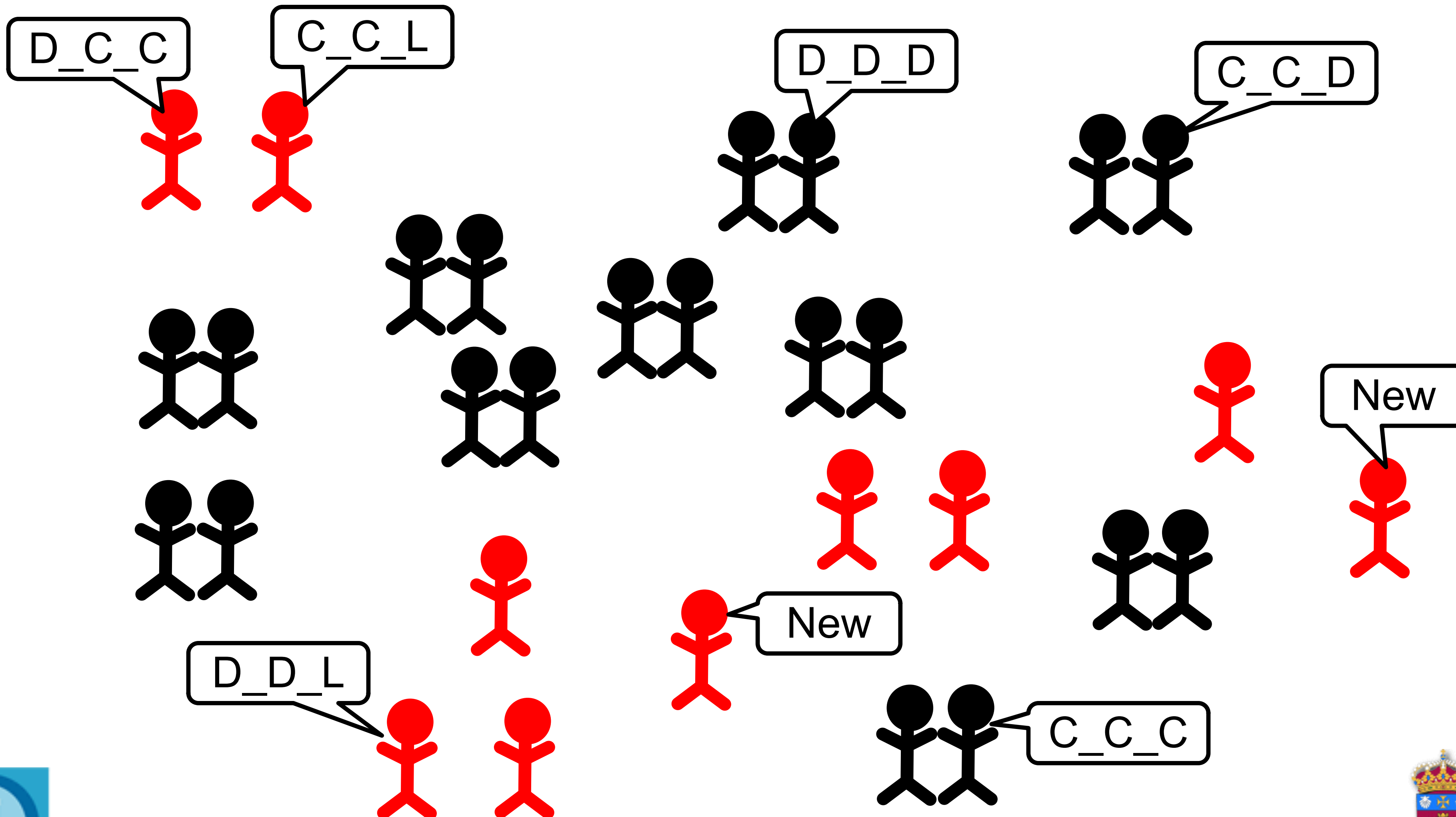
The population for the next step



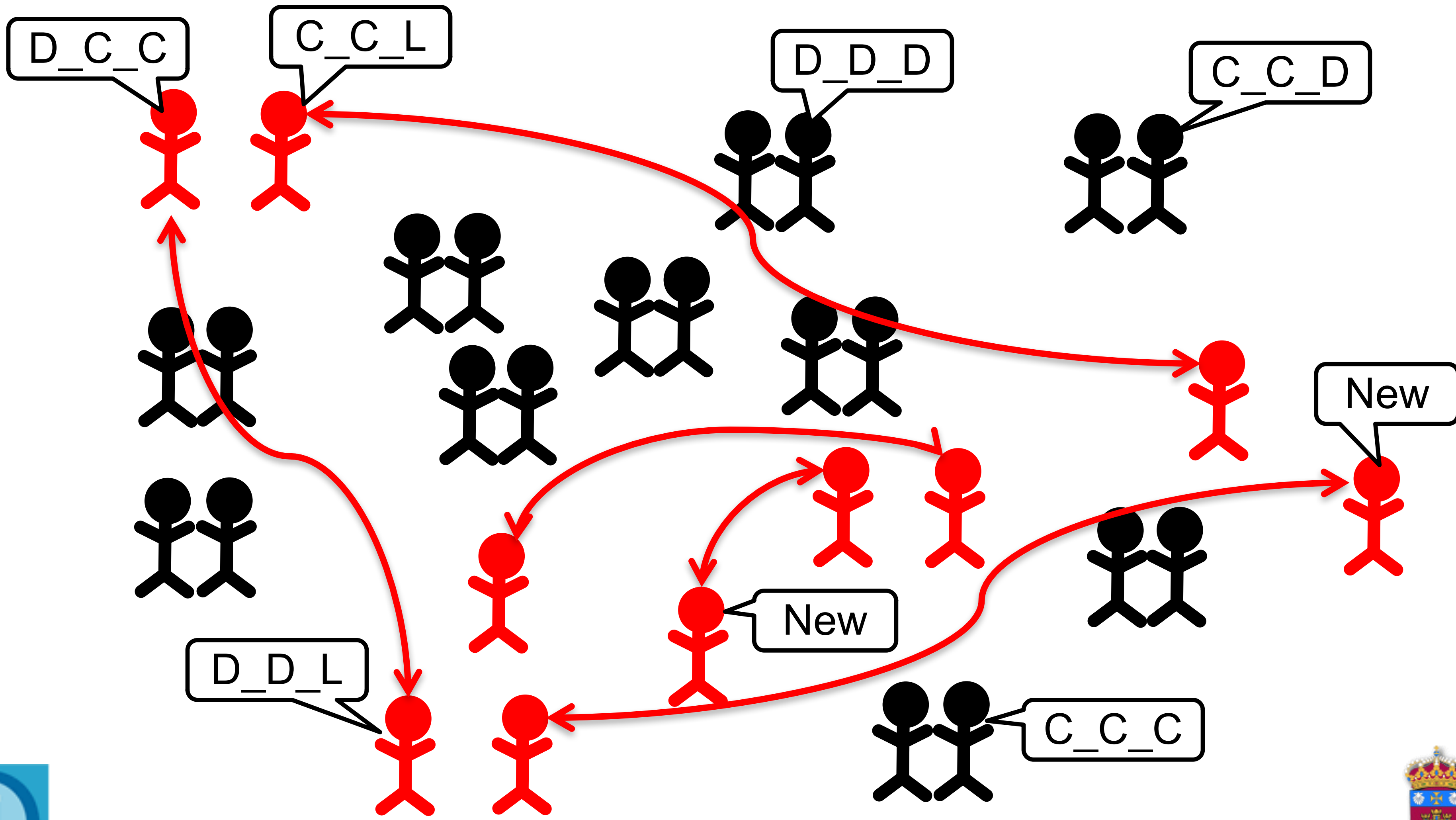
The population for the next step



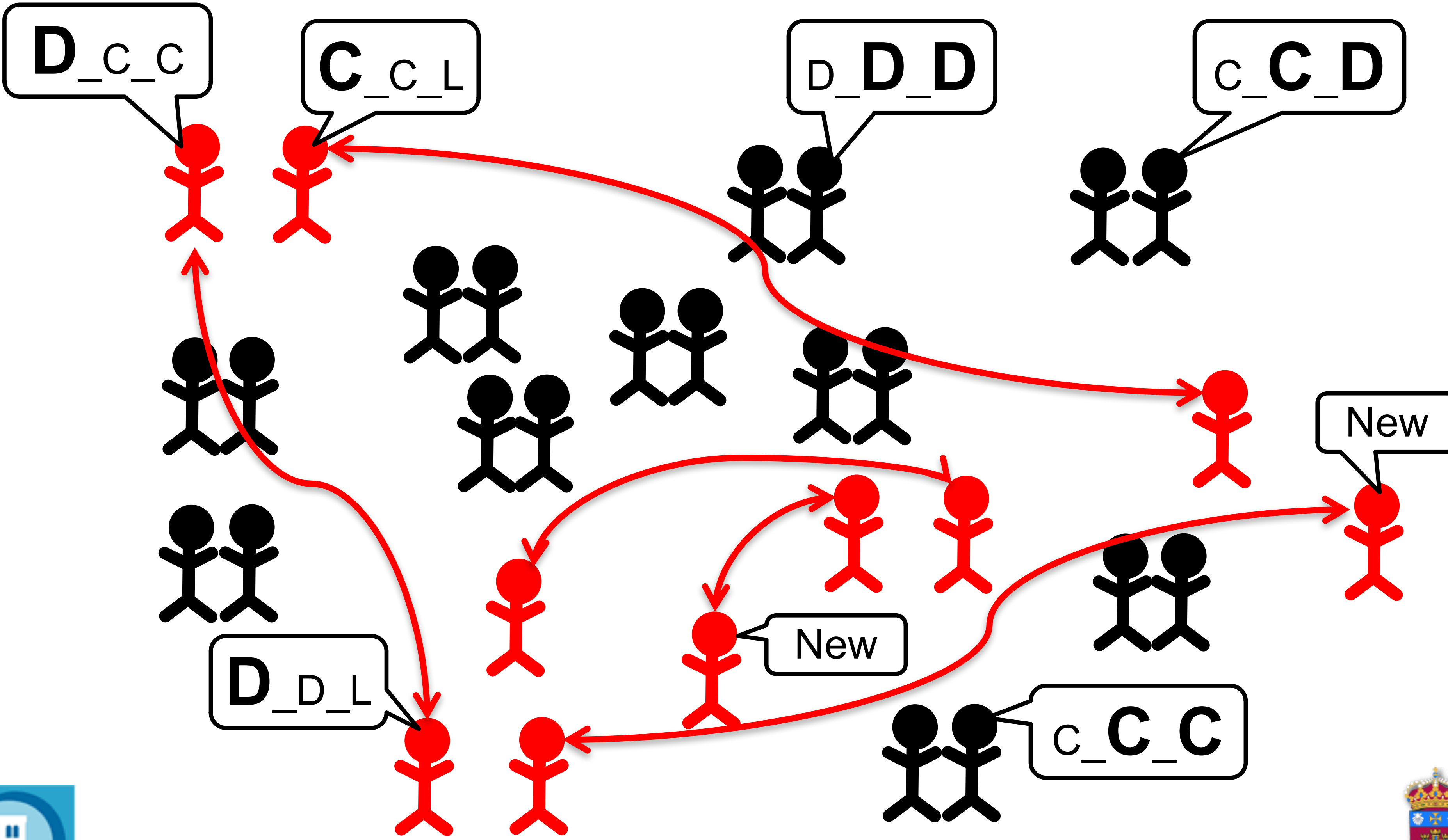
The random pairing of singles



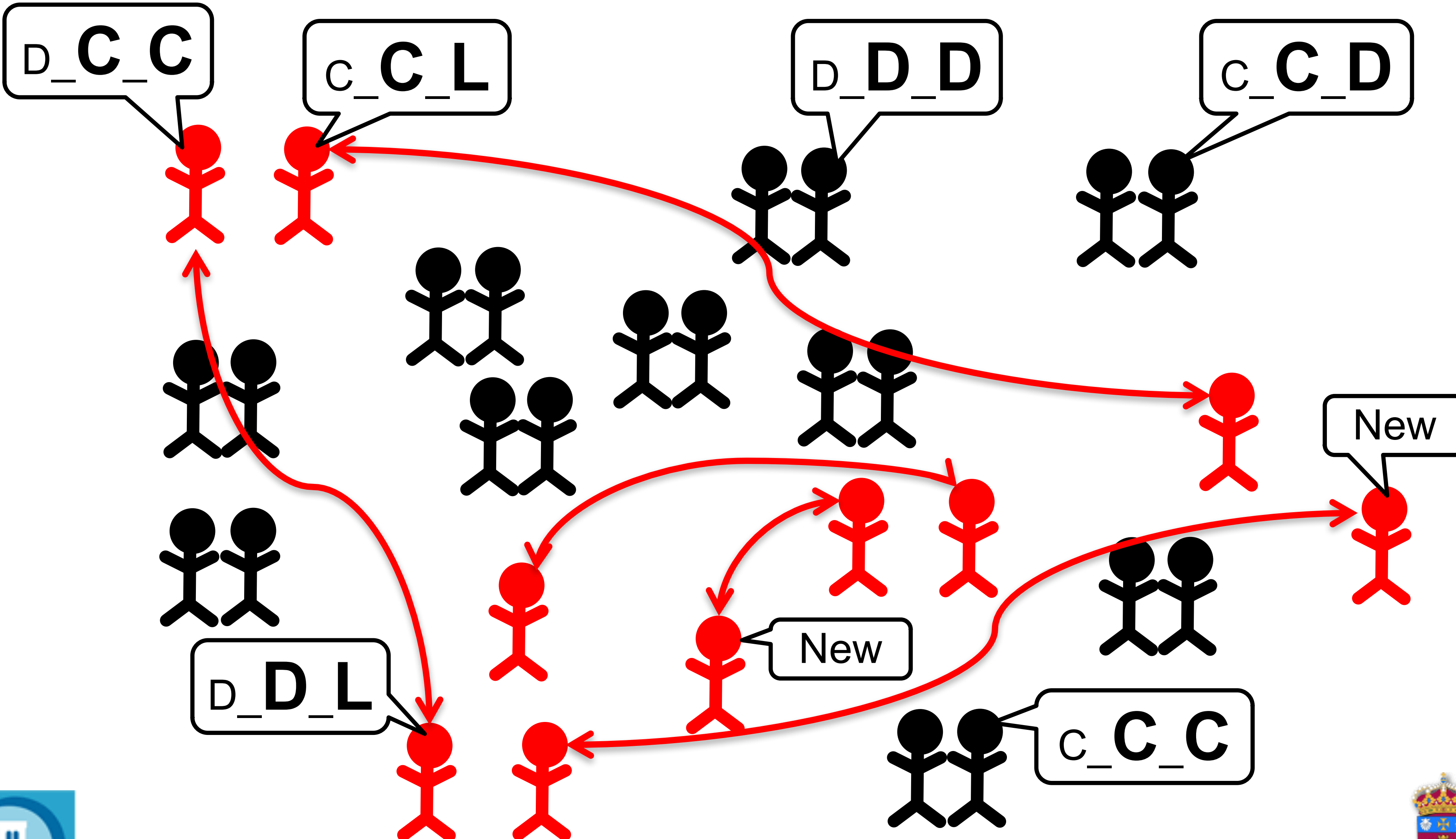
The random pairing of singles



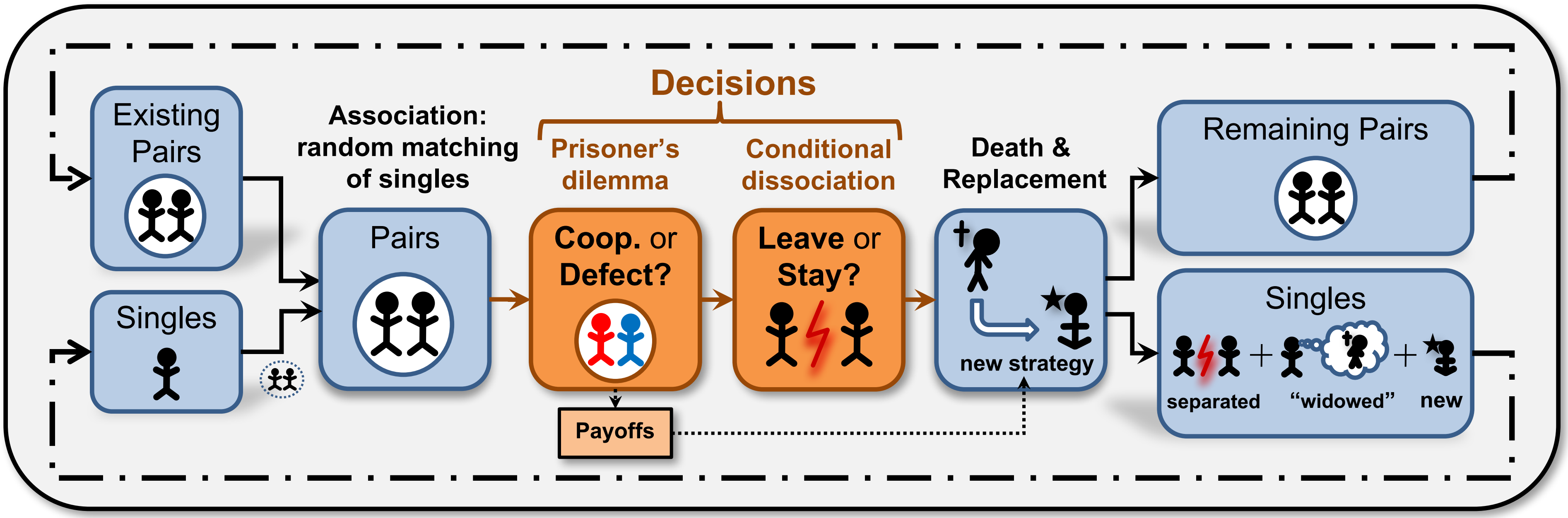
The Prisoner's Dilemma game



Should I stay or should I go?

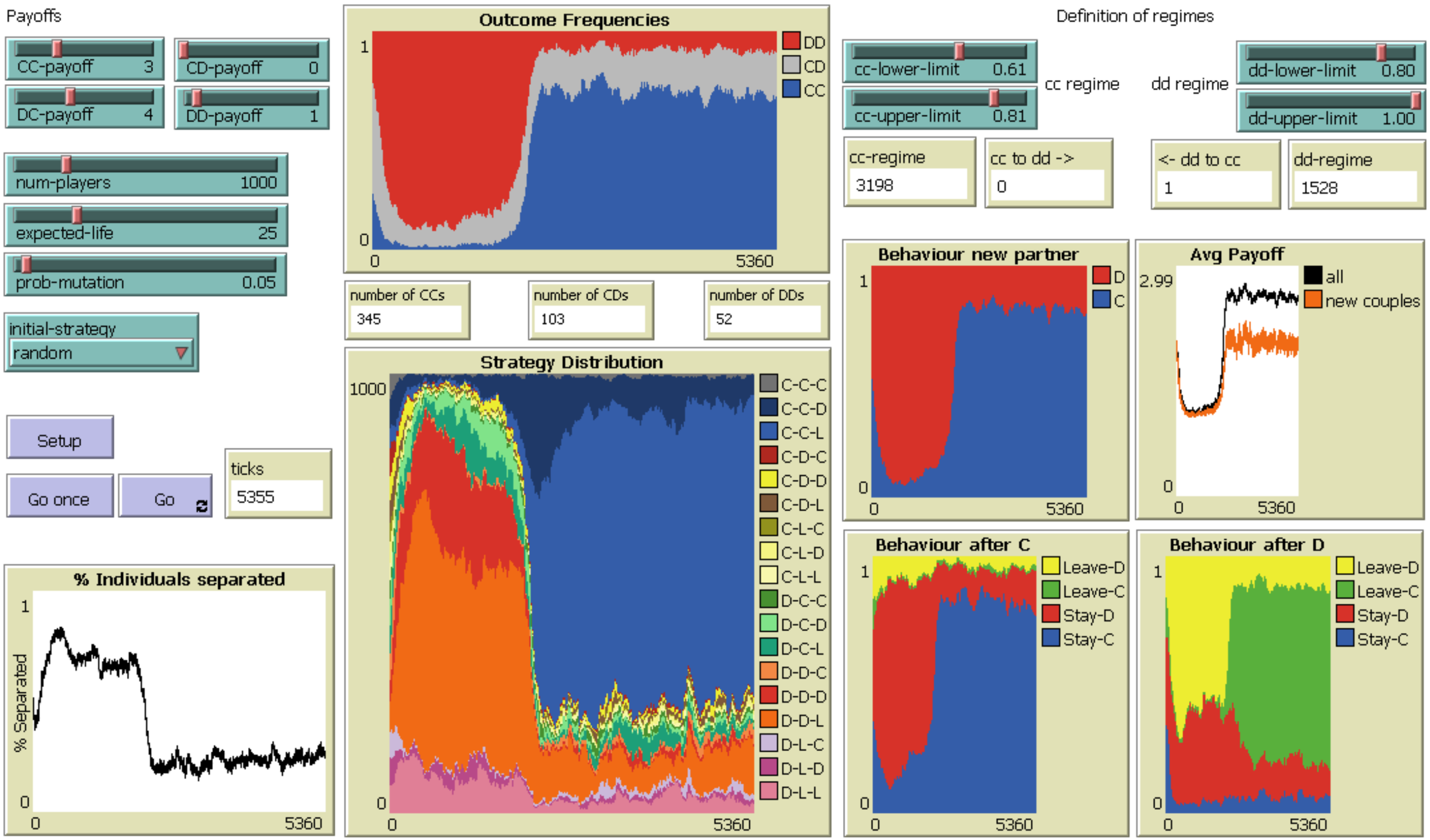


The timeline



Sequence of events within each time period

The implementation of the model



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Three scenarios

Key factor:

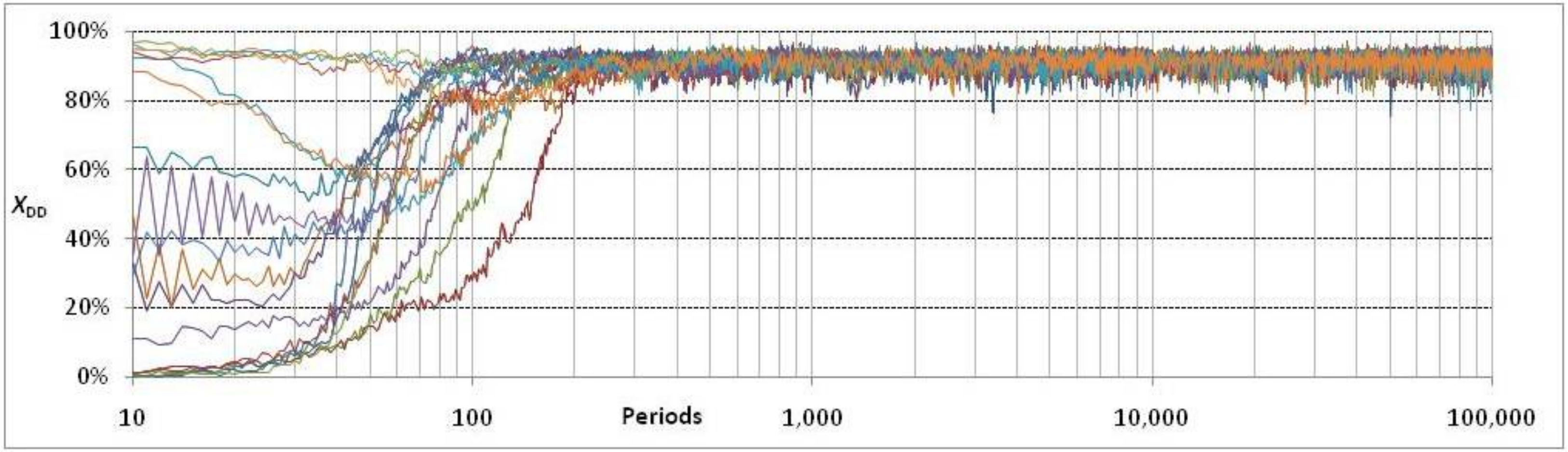
Expected lifespan of the individuals:

- Short life — ***expLife* = 5**
- Long life — ***expLife* = 100**
- Intermediate life — ***expLife* = 20**

Benchmark: $N = 1000$, $\mu = 0.05$, $T = 4$, $R = 3$, $P = 1$, $S = 0$.

Short life: non-cooperative regime

x_{DD} : share of DD outcomes in a period

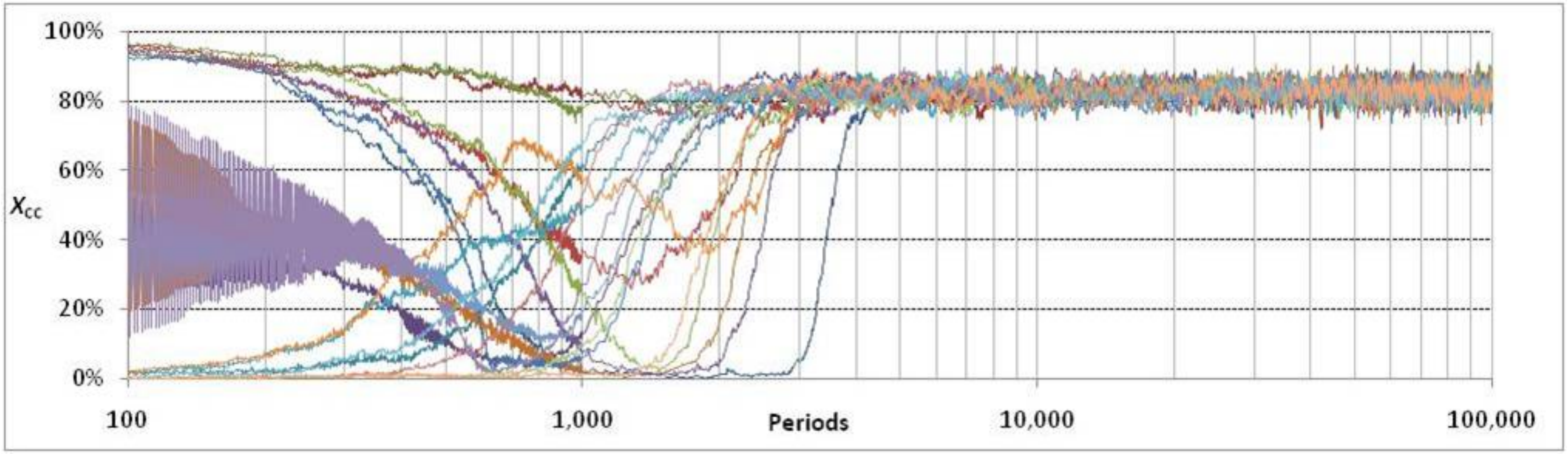


Evolution of the percentage of **DD outcomes** for 18 different runs, each run starting with the whole population using one of the 18 different strategies.

Parameterisation: N = 1000, ***expLife = 5***, μ = 0.05, T = 4, R = 3, P = 1, S = 0.

Long life: cooperative regime

x_{CC} : share of CC outcomes in a period

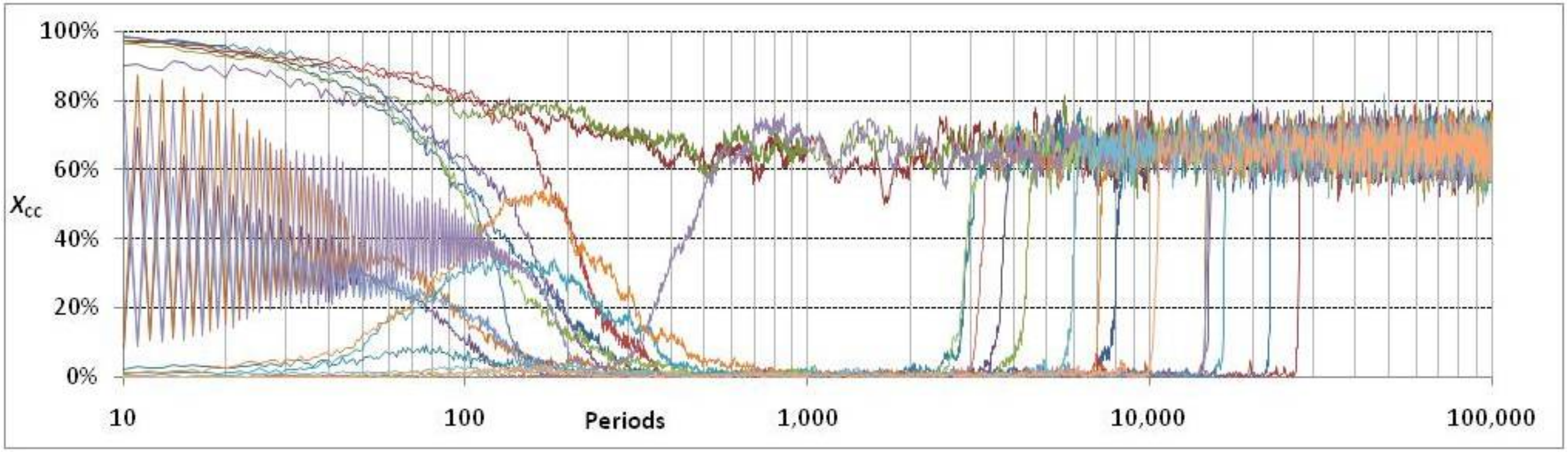


Evolution of the percentage of **CC outcomes** for 18 different runs, each run starting with the whole population using one of the 18 different strategies.

Parameterisation: N = 1000, ***expLife* = 100**, μ = 0.05, T = 4, R = 3, P = 1, S = 0.

Intermediate life: dd-reg -> cc-reg

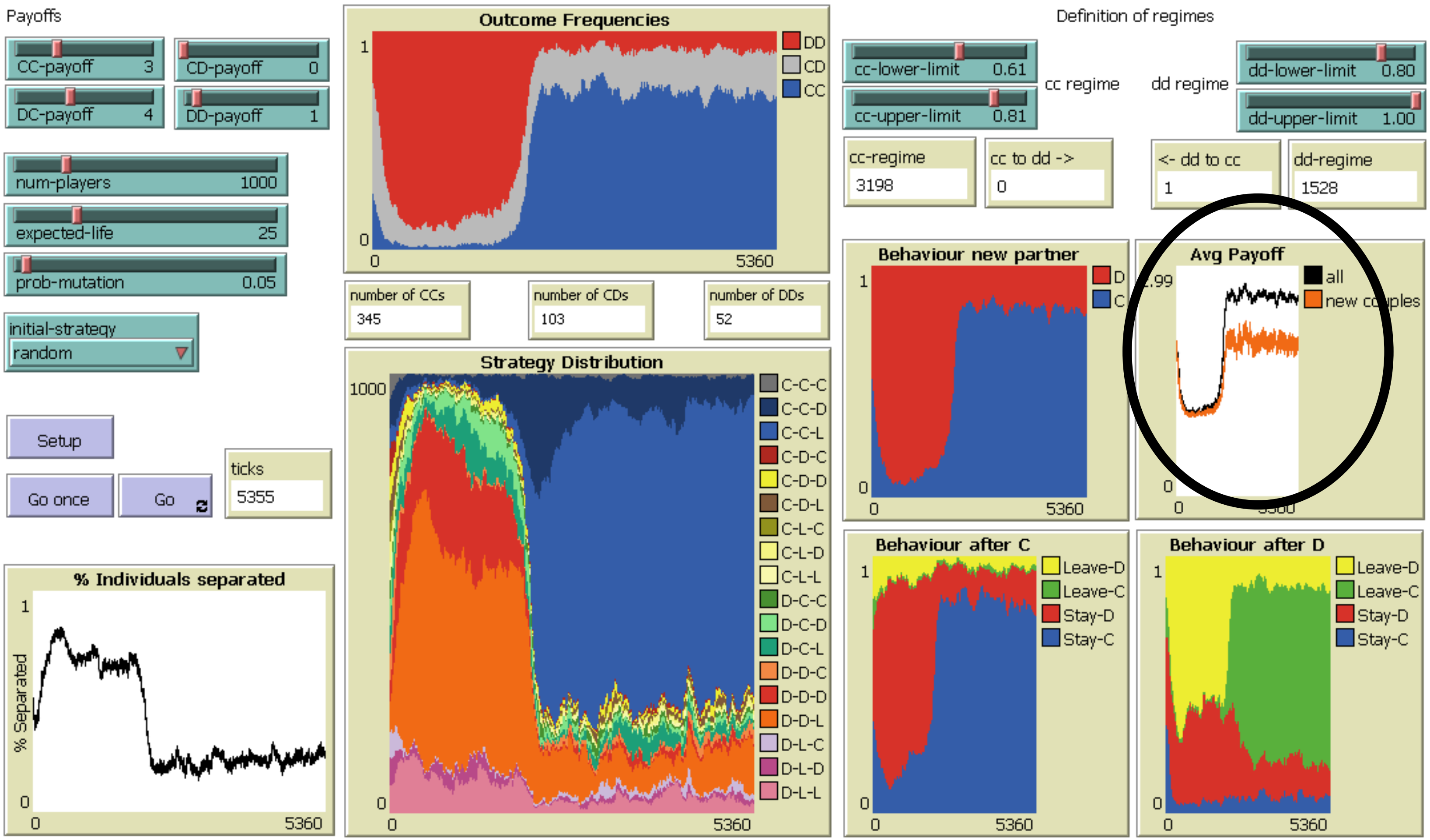
x_{CC} : share of CC outcomes in a period



Evolution of the percentage of **CC outcomes** for 18 different runs, each run starting with the whole population using one of the 18 different strategies.

Parameterisation: N = 1000, ***expLife* = 20**, μ = 0.05, T = 4, R = 3, P = 1, S = 0.

Intermediate life – The 2 regimes

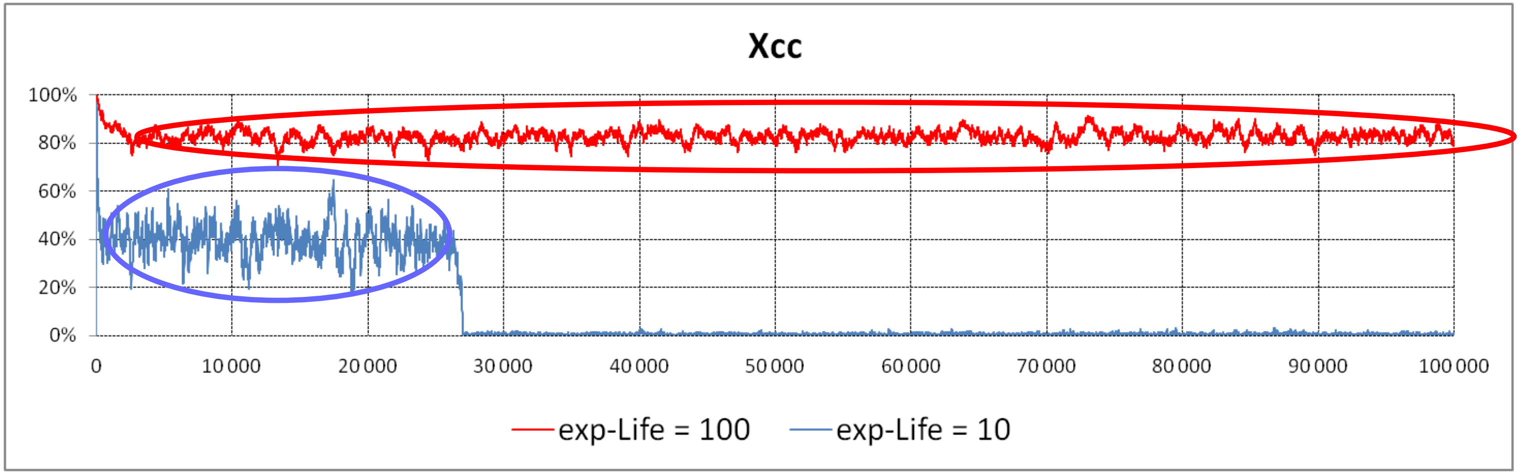


Characterising the 2 regimes

- Non-cooperative regime... Easy:

$$x_{DD} \geq 0.8$$

- (partially) Cooperative regime... not trivial



Need to define a reference value: $\hat{x}_{CC}^{CR}(expLife)$

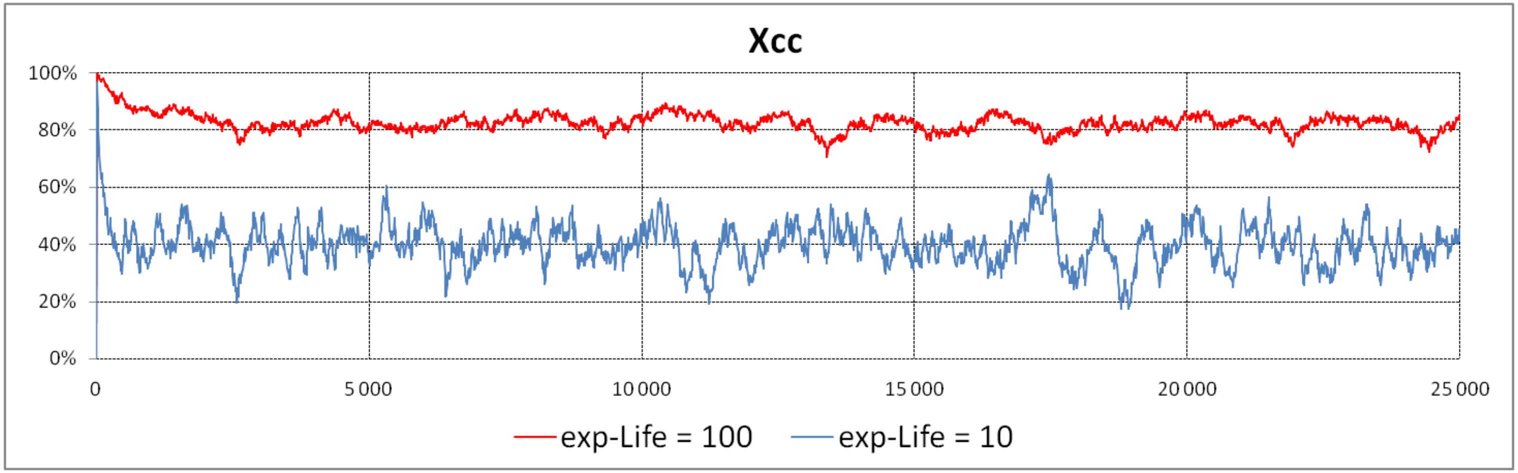
x_{CC} : share of CC outcomes in a period

Characterising the 2 regimes

- Non-cooperative regime... Easy:

$$x_{DD} \geq 0.8$$

- (partially) Cooperative regime... not trivial



Need to define a reference value: $\hat{x}_{CC}^{CR}(expLife)$

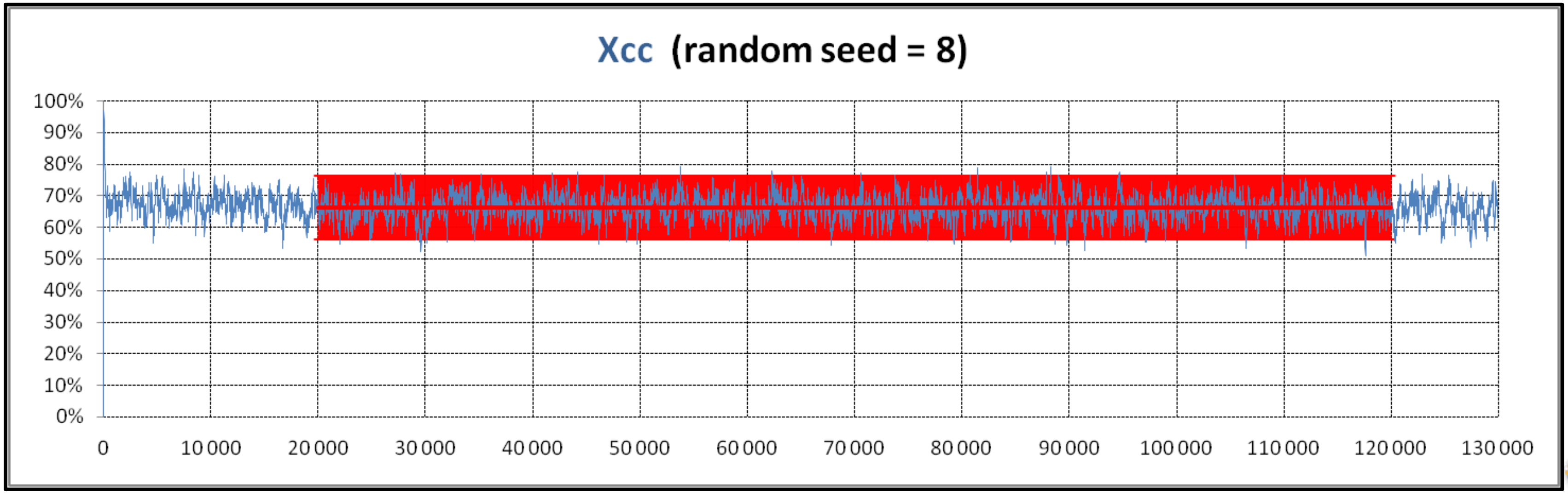
x_{CC} : share of CC outcomes in a period

Characterising the 2 regimes

Definition of the Cooperative regime: $\left| x_{CC} - \hat{x}_{CC}^{CR} \right| \leq 0.1$

where $\hat{x}_{CC}^{CR} = \overline{x}_{CC}$ in a series between periods 20 001 and period 120 000

provided:
- $\overline{x}_{CC} \geq 0.2$
- At least 99% samples satisfy $\left| x_{CC} - \overline{x}_{CC} \right| \leq 0.1$



Characterising the 2 regimes

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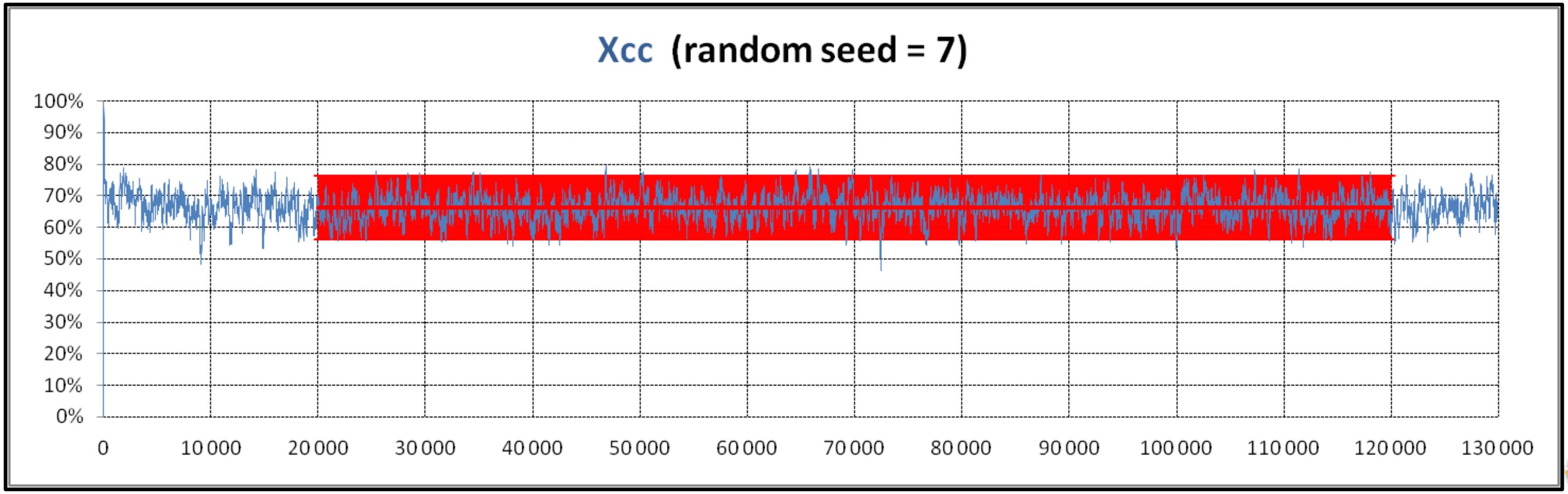
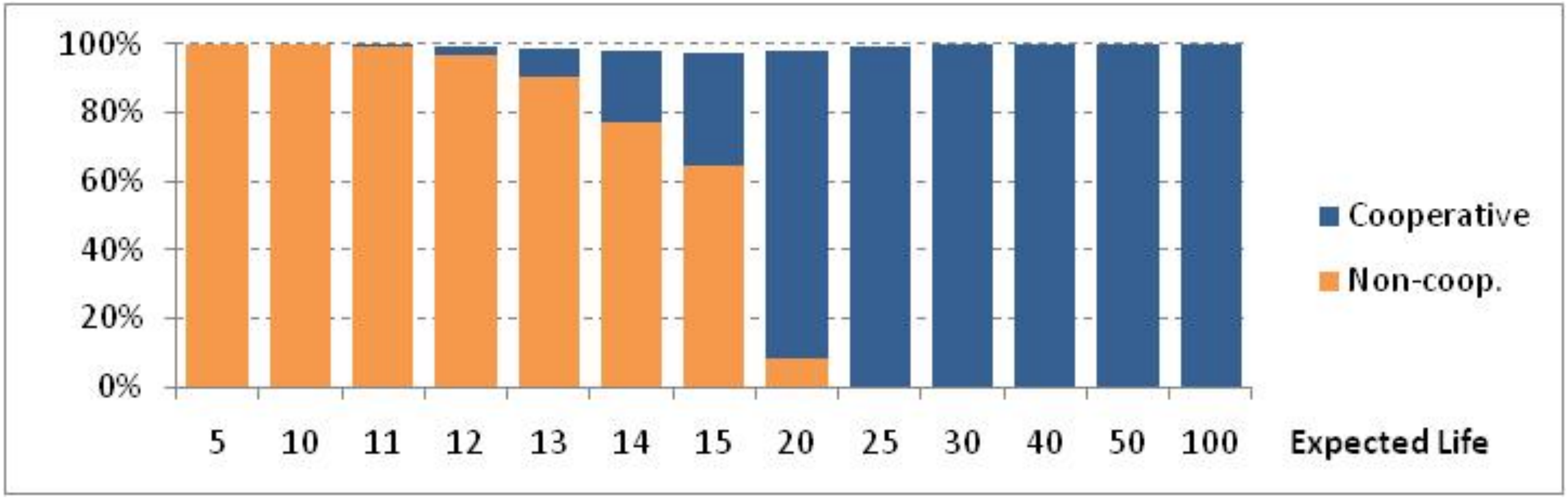


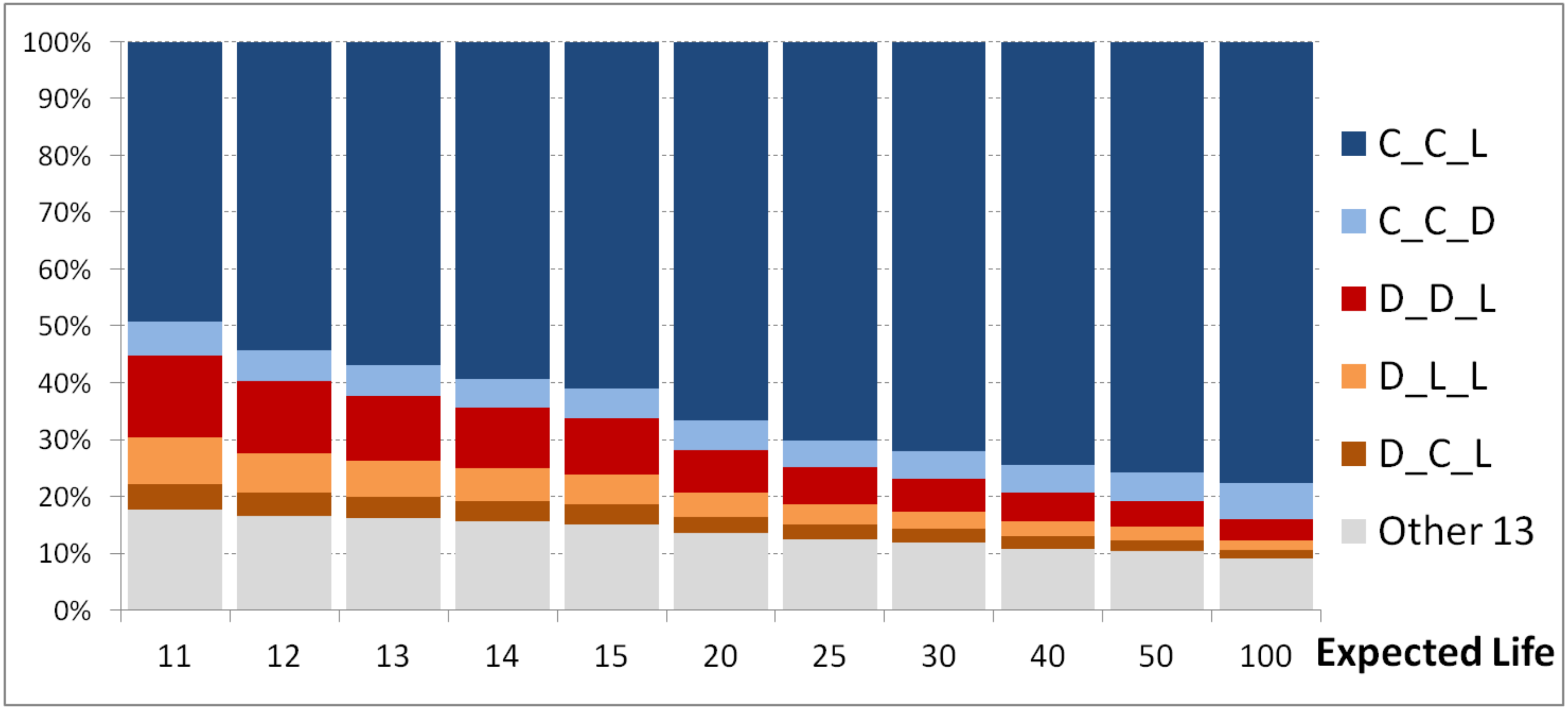
Results



Fraction of periods spent in the cooperative and in the non-cooperative regimes as a function of the expected life *expLife*.

The values in each column are compiled over 10^3 simulation runs.
Every run measured between periods $3 \cdot 10^3$ and 10^4, with random initial conditions.
Parameterisation: $N = 1000$, $\mu = 0.05$, $T = 4$, $R = 3$, $P = 1$, $S = 0$.

Distribution of Strategies in the cooperative regime



Expected Life and discount factor

Probability that both individuals in a pair survive to the next period:

$$(1 - 1/L)^2$$

If there wasn't the option to leave, the effective discount factor would be:

$$\delta = (1 - 1/L)^2$$

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Mean-field approximation

Time-homogeneous Markov chain

Ergodic if *expLife* < ∞ and $\mu > 0$.

Mean-field approximation

Time-homogeneous system of ordinary differential equations with hundreds of state variables.

Reduced mean-field approximation to calculate the level of cooperation in the cooperative regime

Focus only on the strategies that the numerical simulations single out as the most prevalent in the cooperative regime: **C_C_L and family D_X_L**.

Mean-field approximation

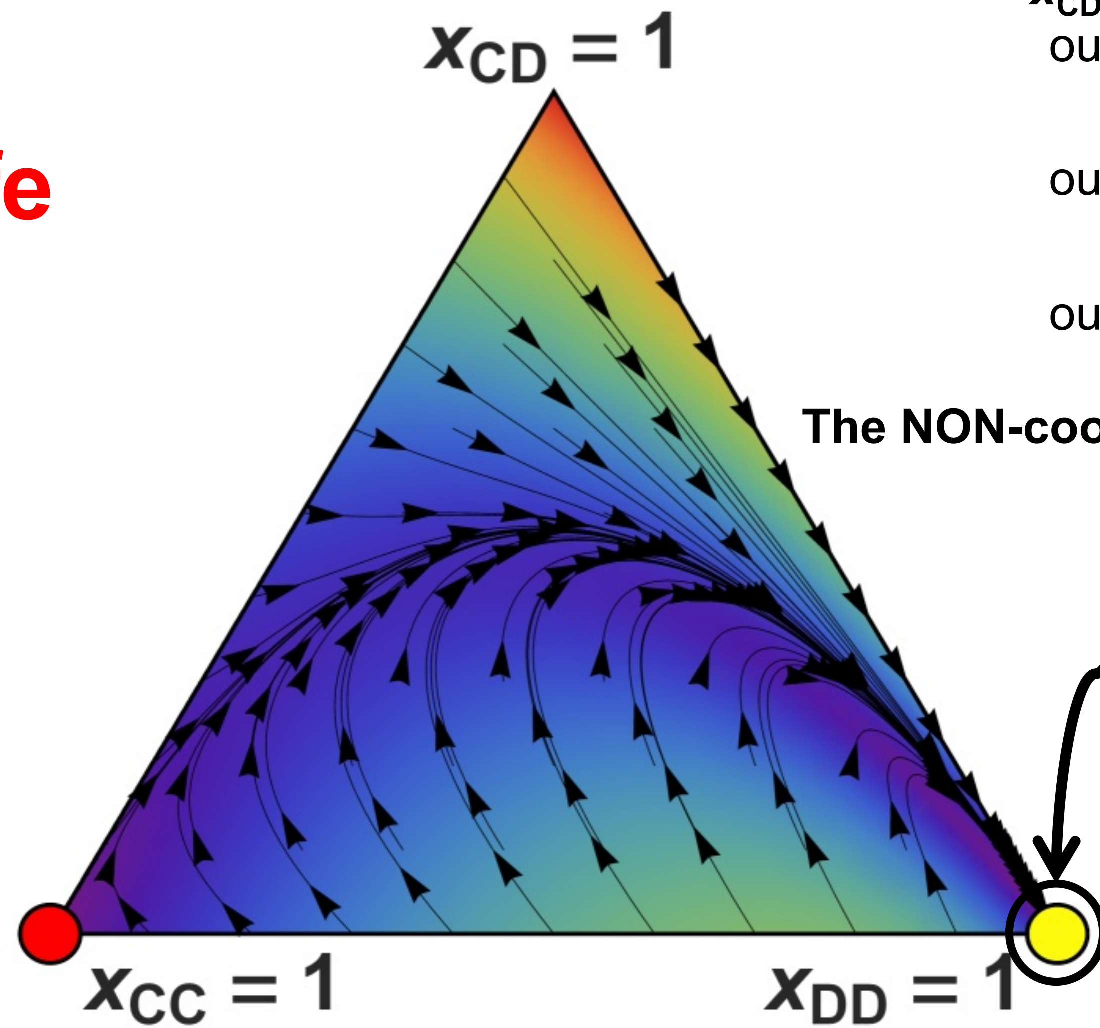
Short life

expLife = 1

x_{CD} : share of CD, DC outcomes in a period

x_{CC} : share of CC outcomes in a period

x_{DD} : share of DD outcomes in a period



Mean-field approximation

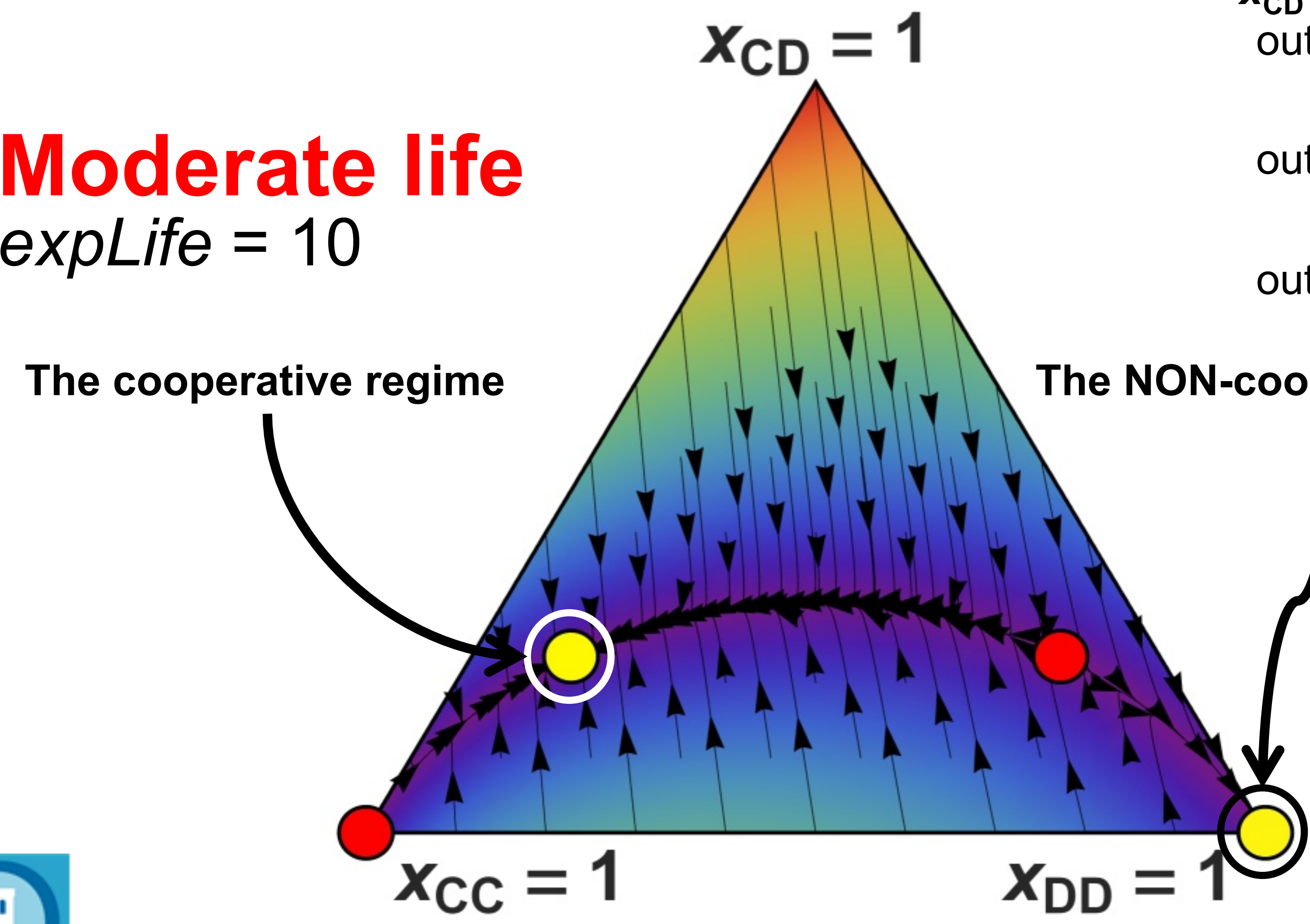
x_{CD} : share of CD, DC outcomes in a period

x_{CC} : share of CC outcomes in a period

x_{DD} : share of DD outcomes in a period

Moderate life

expLife = 10



Mean-field approximation

x_{CD} : share of CD, DC outcomes in a period

x_{CC} : share of CC outcomes in a period

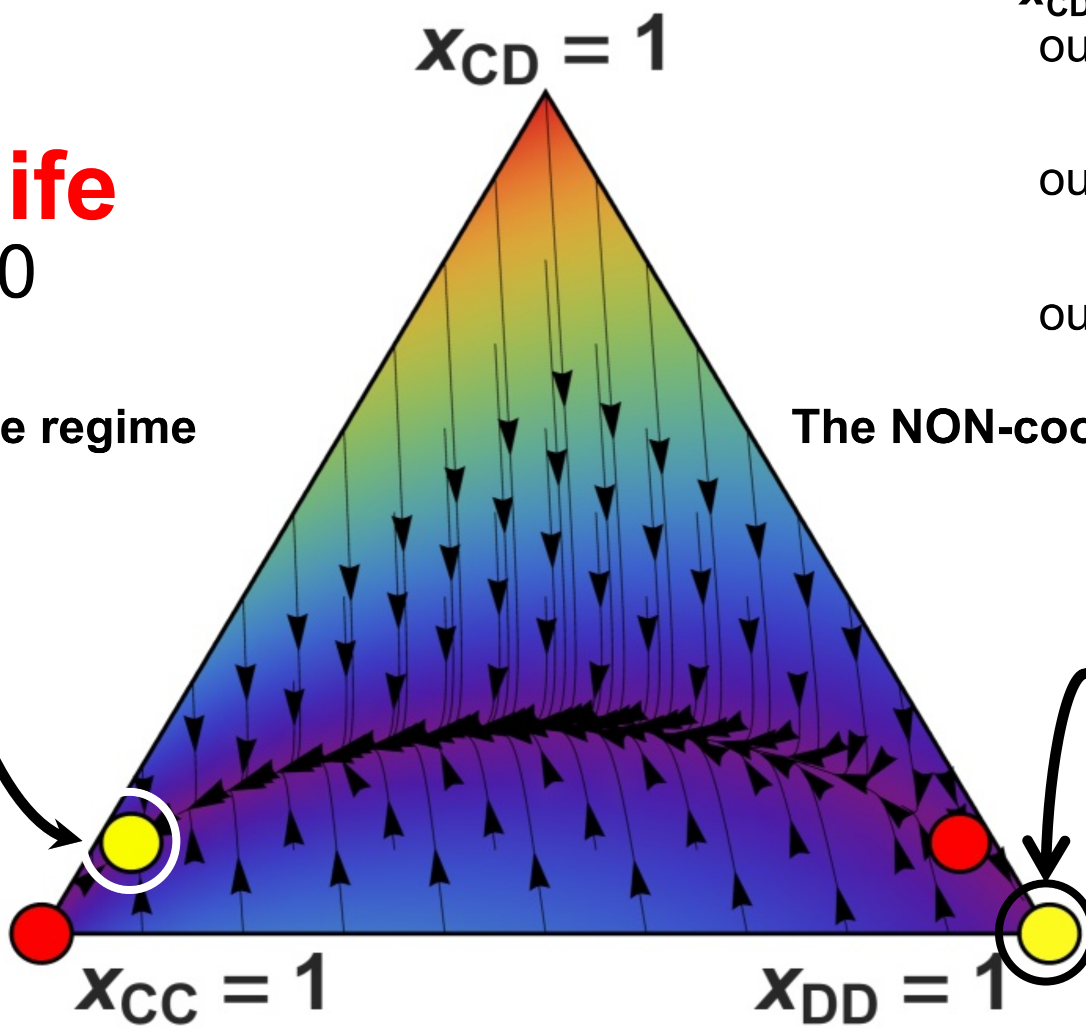
x_{DD} : share of DD outcomes in a period

Longer life

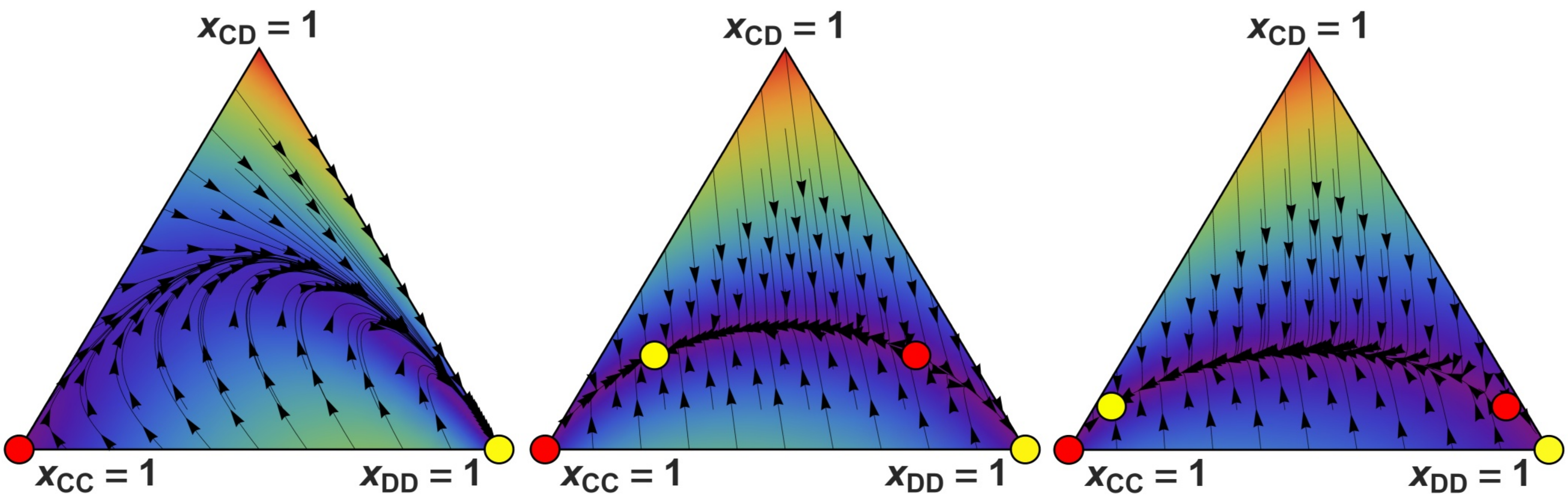
expLife = 20

The cooperative regime

The NON-cooperative regime



Mean-field approximation

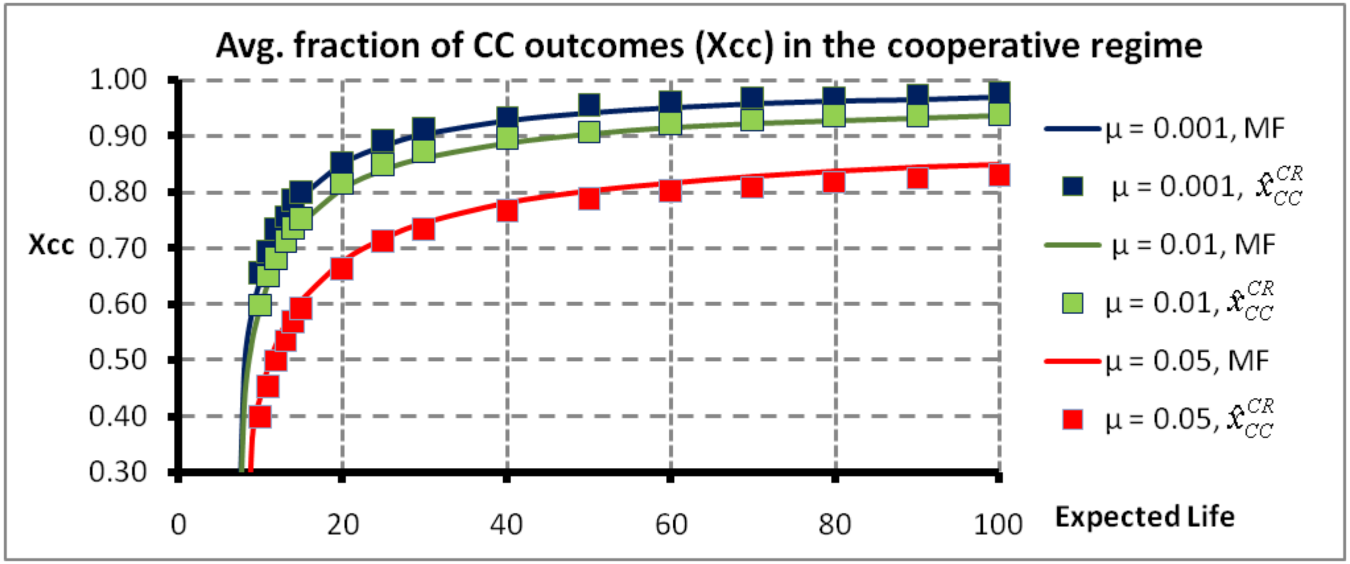


Short Life — *expLife* = 1

Moderate Life — *expLife* = 10

Longer Life — *expLife* = 20

Mean-field approximation



Average values of the level of cooperation (x_{CC}) in the cooperative regime as a function of the individuals' expected life *expLife*, both in the mean-field approximation and in the stochastic simulations with different values of μ.

Parameterisation: $N = 1000$, $T = 4$, $R = 3$, $P = 1$, $S = 0$.

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Conclusions

- A simple mechanism of conditional dissociation can explain the evolutionary emergence of cooperation.
- Key factor: expected lifespan of the individuals.
  It is sufficient that lifespans are only moderately long.
- Cooperative regime mostly composed of "*conditional dissociators*", even in the presence of more popular strategies like Tit-For-Tat.

Should I stay or should I go?

Conditional dissociation in the Evolutionary Emergence of Cooperation

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Luis R. Izquierdo University of Burgos (Spain)

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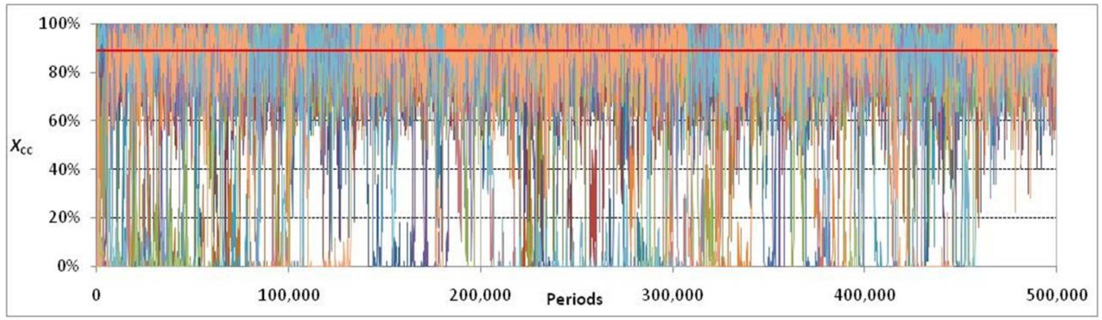
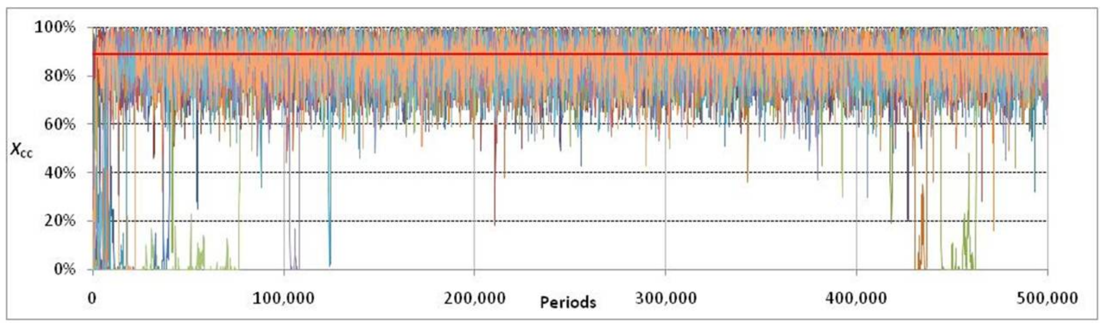
Different populations

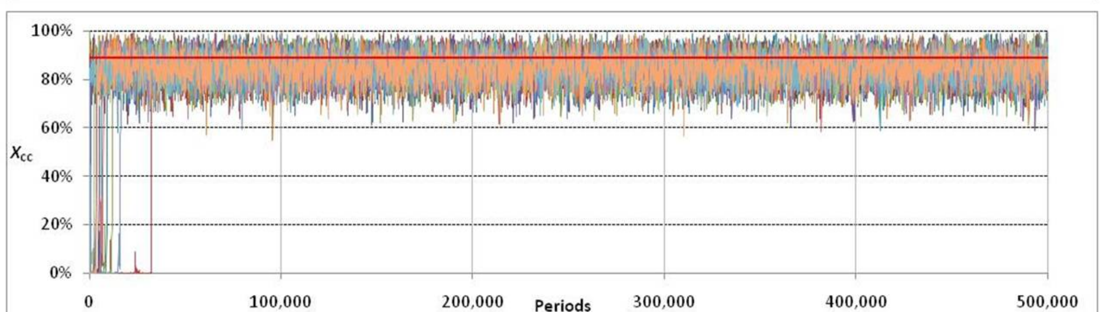
N = 100



N = 200

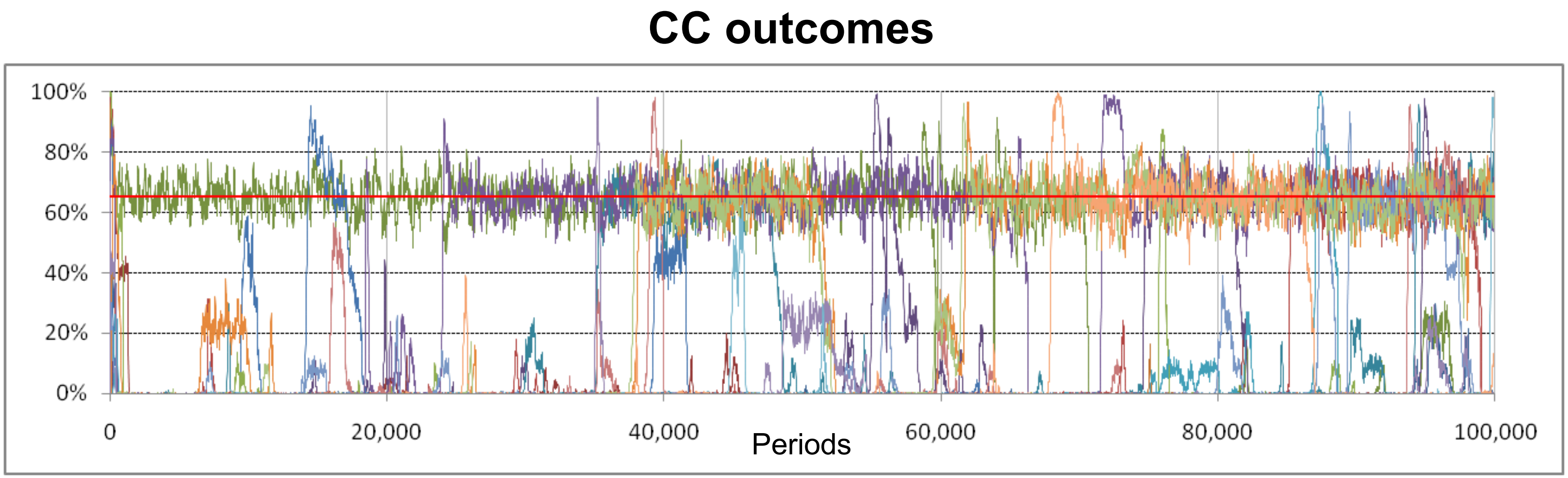


N = 400



expLife = 25, μ = 0.01, T = 4, R = 3, P = 1, S = 0.
The horizontal line at x_{CC} = 89% shows the stable degree of cooperation in the mean-field approximation

Regime changes



N = 1000, *expLife* = 10, μ = 0.001, *T* = 4, *R* = 3, *P* = 1, *S* = 0.
The horizontal line at x_{CC} = 65.5 % shows the stable degree of cooperation in the mean-field approximation