Cooperation in Social Dilemmas

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The Roxburghe Ballads 1874

I. Punishment & reputation

II. Voluntary participation

III. Volunteering & punishment

The problem of cooperation

Examples

- Group defense and foraging
- Predator inspection, alarm calls
- Major transitions in the evolution of life.
- Social welfare
- Global sustainability

↳ Conflict of interest between individual and community performance.

Public Goods Games

Definition

- Two strategic types
    - cooperators - contribute to common pool at cost c.
    - defectors   - contribute nothing

- Players interact in groups of size N.

- Total contributions are multiplied by r and equally split among all participants (irrespective of their type):

$$P_d = \frac{rc}{N} n_c \qquad n_c\text{: number of cooperators among co-players}$$

$$P_c = P_d - (1 - \frac{r}{N})c$$

↳ For $r < N$, defectors are always better off.

Public Goods Games

Population dynamics

- ◼ Dynamics of cooperators and defectors in large populations.
- ◼ Payoffs translate into reproductive fitness.
- ◼ Frequency of cooperators x:

$$\dot{x} = x(P_x - \bar{P})$$
$$= x(1 - x)(P_x - P_y)$$

- ↳ Cooperators disappear if $r < N$, $x = 0$ is stable.
- ↳ Defectors disappear if $r > N$, $x = 1$ is stable.
- ↳ Co-existence never occurs.

Punishment

Promoting cooperation - part I

- Punishment ubiquitous in nature
    - toxin production in bacteria
    - policing in social insect
    - fights for rank
    - 👆 punishment is costly
- Three strategic types
    - cooperators x
    - defectors y
    - punishers w

👆 cooperators pave the way for defectors

👆 defection only stable state
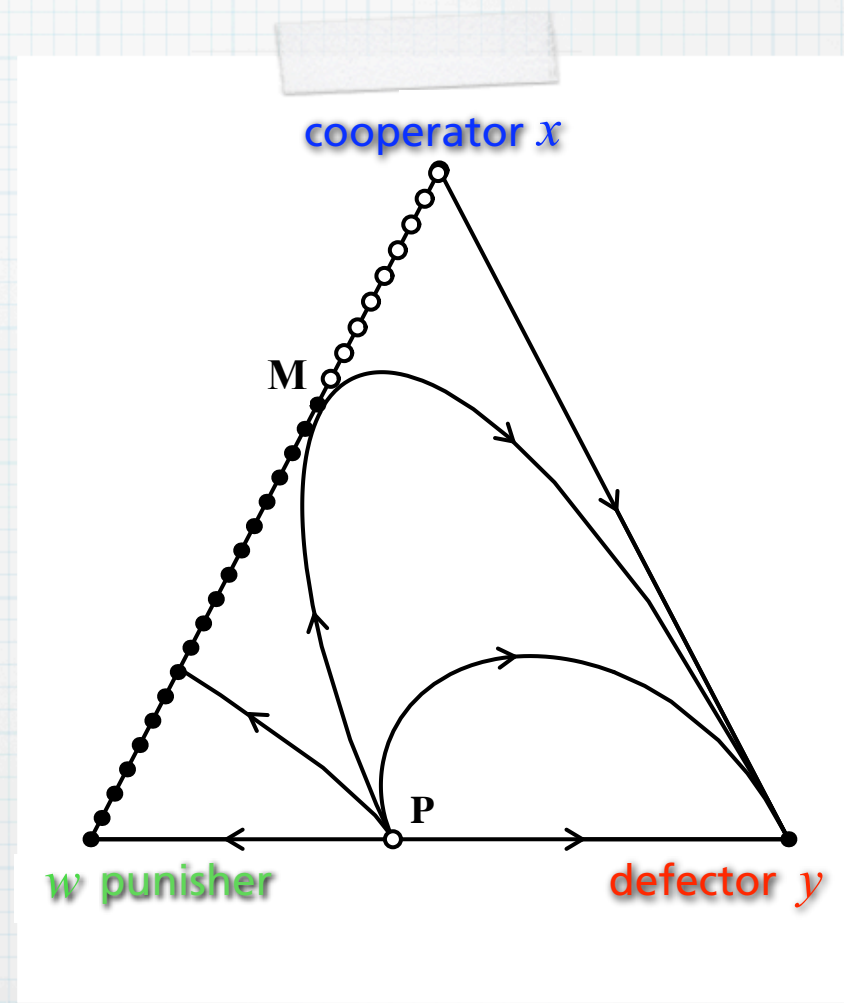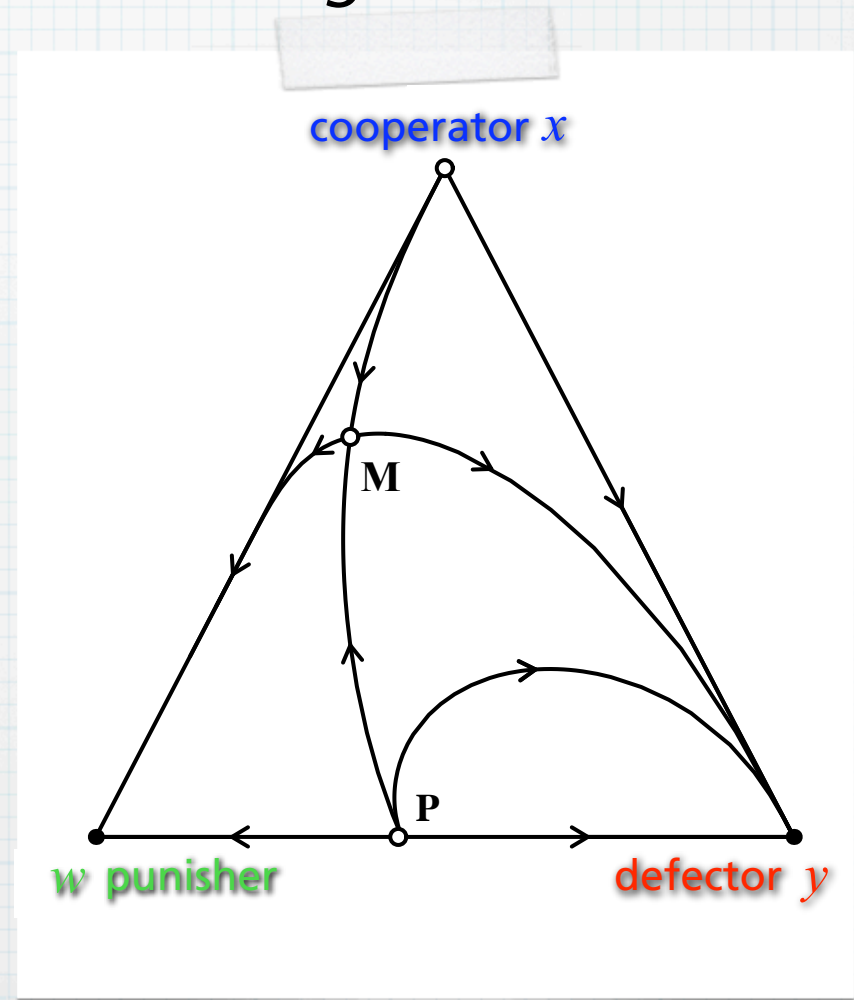
Reputation

Public goods games with second thoughts

- Punishing behavior of partners may become known and players may adapt their response.
- Contributors may
  - a. know the reputation of their partners
  - b. switch to defection, if they can get away with it.

↳ bi-stability - defector and punisher states are both stable.

↳ evolutionary end state depends on initial configuration.

cooperator x

M

P

w punisher   defector y

Punishment & Reputation

Conclusions

- Punishment alone is insufficient to stabilize cooperation.

- Reputation and conditional responses required.

↳ "We seem to have replaced the problem of explaining cooperation with that of explaining altruistic punishment."

Colman, *Nature* 2006

*Sigmund, Hauert & Nowak (2001) PNAS **98** 10757.*
*Hauert, Haiden & Sigmund (2004) DCDSB **4** 575.*

Voluntary participation

Promoting cooperation - part II

- Participation in public goods interactions is voluntary.
- Three strategic types
  - cooperators x
  - defectors y
  - loners (non-participants) z
- Loners have fixed payoff σ with

  $0 < \sigma < (r - 1)c$.

- escape hatch out of mutual defection.
- simple yet effective.
- maintains cooperation but fails to stabilize it.

cooperator x

$r > 2$

z loner

defector y
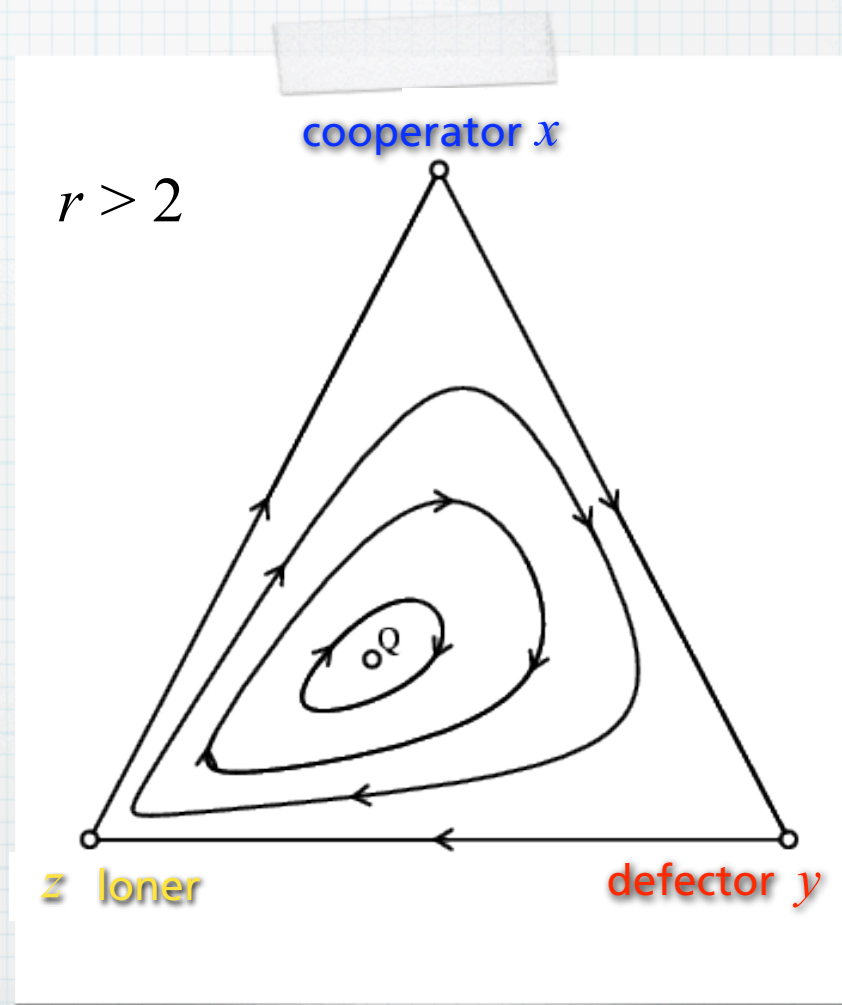
Volunteering

Conclusions

- Volunteering promotes cooperation but cannot stabilize it.

↳ "To face immense perils, volunteers are infinitely preferable to a body of men under orders."

Memoirs of Marbot (an officer of Napoleon)

*Hauert, De Monte, Hofbauer & Sigmund (2002) Science **296** 1129.*
*Hauert, De Monte, Hofbauer & Sigmund (2002) J. theor. Biol. **218** 187.*

Volunteering & Punishment

Promoting cooperation - part III

- ◻ Voluntary public goods games with punishment.

- ◻ Four strategic types
  - ◼ cooperators x
  - ◼ defectors y
  - ◼ loners (non-participants) z
  - ◼ punishers w

- ⇨ bi-stability - edge wM and plane xyz stable.
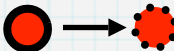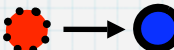- ⇨ structurally unstable.

punisher
w

z loner

P

y
defector

M

x
cooperator
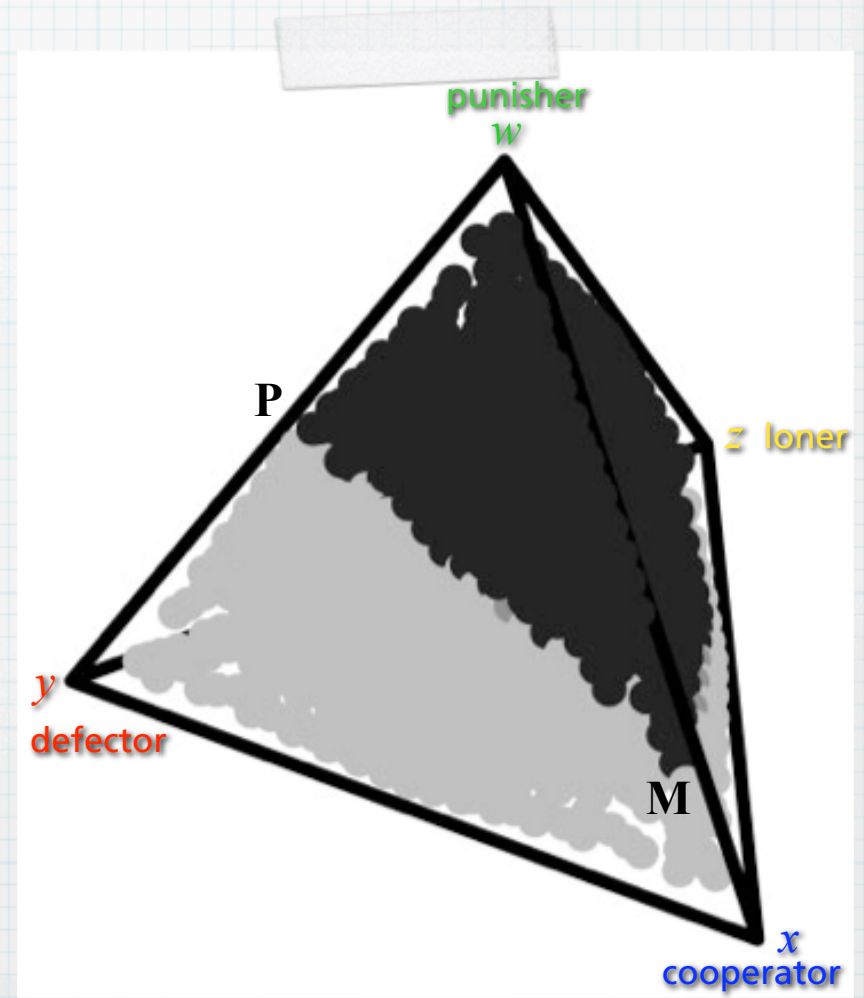
Finite Populations

Birth-death process (Moran)

- Fitness of strategy i:

  $1 - s + s\,P_i$

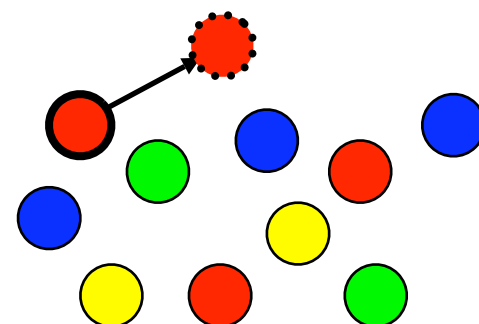 s selection strength, P_i payoff.

- *Birth*: reproduction proportional to fitness.

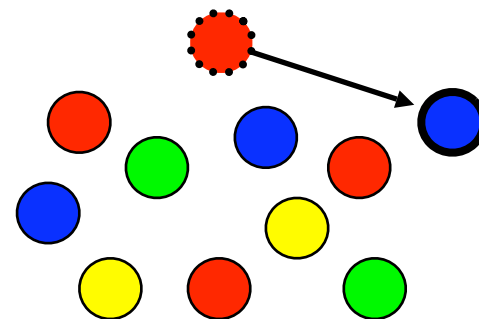- *Death*: replacement of random individual.

⇨ balance between selection and random drift.

⇨ for rare mutations population mostly homogeneous.
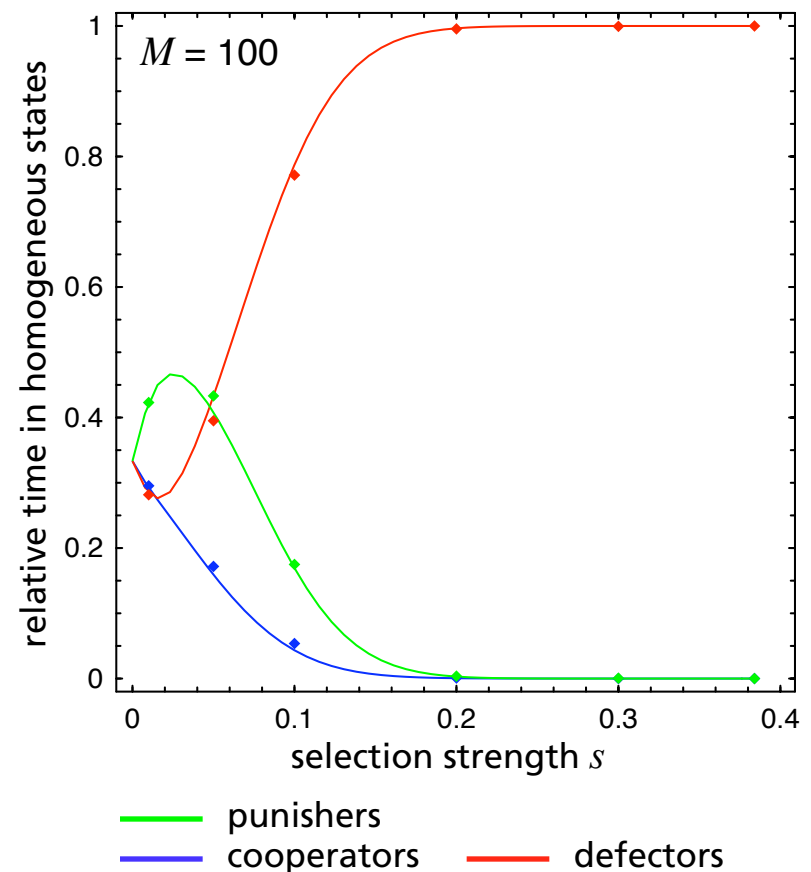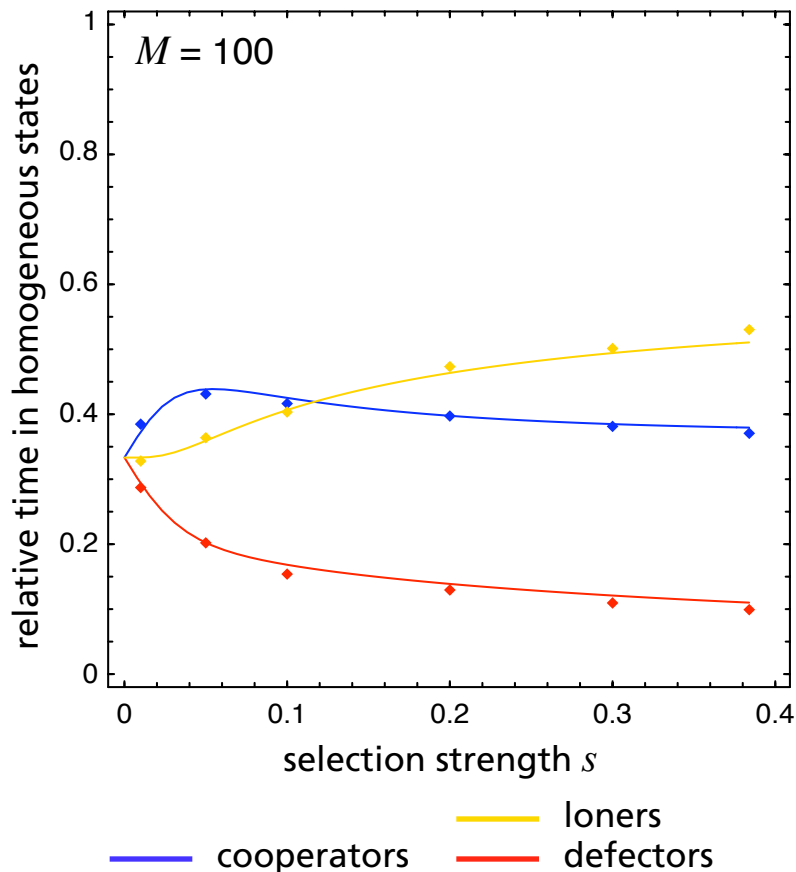

Birth

Death

Volunteering & Punishment

Results

- Punishers dominate.
- Defectors largely eliminated.
- For weak selection, all states become equally likely.

↳ cooperation (and punishment) is favored.

↳ loners provide recurrent opportunities for establishing cooperation (and punishment).

↳ contrasts with expectations based on infinite dynamics.

$M = 100$

relative time in homogeneous states vs. selection strength s

- punishers
- cooperators
- loners
- defectors
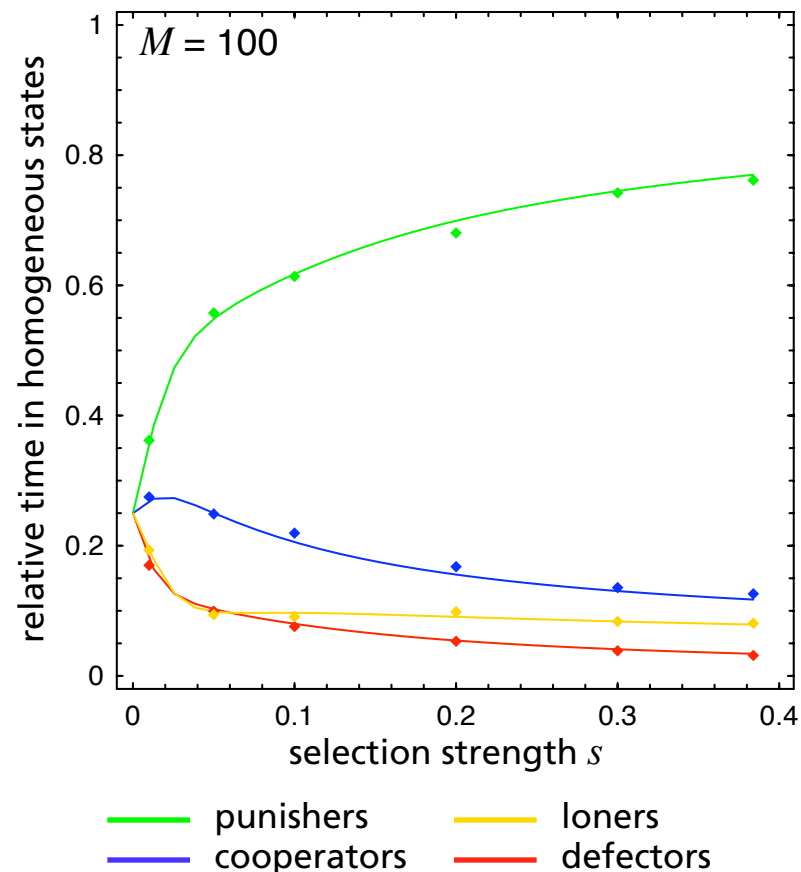
Volunteering & Punishment

Results - three strategies only

The problem of cooperation

Conclusions

🟨 Combined efforts of punishment and volunteering:
👇 dynamics remains bi-stable in infinite populations.

🟨 Stochastic dynamics in finite populations resolve the problem of altruistic punishment:
👇 population spends most time in punishment state.

🟨 Punishment often fails in compulsory public goods
👇 preservation of global resources (climate, air, water, fish...).

🟨 Enforcement of cooperation (punishment of cooperators or loners) decreases efficiency of public goods.
👇 "Mutual coercion mutually [and voluntarily] agreed upon".

(Hardin, 1968)

*Brandt, Hauert & Sigmund (2006) PNAS **103** 495.*
*Hauert, Traulsen, Brandt, Nowak & Sigmund (2007) Science **316** 1905.*

Acknowledgments

… Upon this a question arises: whether it be better to be loved than feared or feared than loved? … because it is difficult to unite them in one person, it is much safer to be feared than loved … for love is preserved by the link of obligation which … is broken at every opportunity for their advantage; but fear preserves you by a dread of punishment which never fails.

Machiavelli, The Prince