Evolutionary Dynamics in a Group Population Structure

With Barriers to Group Entry

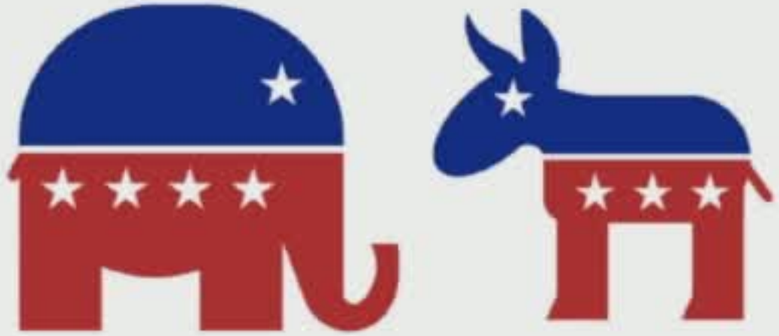
Olivia J. Chu*, Vítor V. Vasconcelos, Corina E. Tarnita

Program in Quantitative and Computational Biology (QCB)
Department of Ecology and Evolutionary Biology (EEB)
Princeton University

SIAM DS19
May 21st, 2019

Groups

Human society is organized in groups:



Overview

Model setup: evolutionary set theory

Setup

A population of N individuals distributed over M sets.

Interactions

Individuals interact in a pairwise fashion with other individuals who share the same sets through an *evolutionary game*. Two individuals interact as many times as the number of sets they have in common. There is no self-interaction.

Payoffs and Fitness

At each discrete time step, individuals accumulate a total payoff, p. The *fitness*, f, of an individual depends on payoff, and is given by

$$f = 1 + \delta p$$

where δ corresponds to the intensity of selection (how much the game contributes to fitness). The limit of *weak selection* is given by $\delta \to 0$, and the special case of $\delta = 0$ corresponds to neutral drift.

The state, S, of a system

The state S is given by a vector $\vec{s}$, and a matrix, H:

Strategy vector, $\vec{s}$

The ith entry of $\vec{s}$ gives the strategy of individual i:

$$s_i = \begin{cases} 0, & \text{if } i \text{ is a defector} \\ 1, & \text{if } i \text{ is a cooperator} \end{cases}$$

The state, S, of a system

Set membership matrix, H

H is an $N \times M$ matrix whose ij-th entry gives information about the set memberships of individual i:

$$H_{ij} = \begin{cases} 1, & \text{if } i \text{ belongs to set } j \\ 0, & \text{otherwise} \end{cases}$$

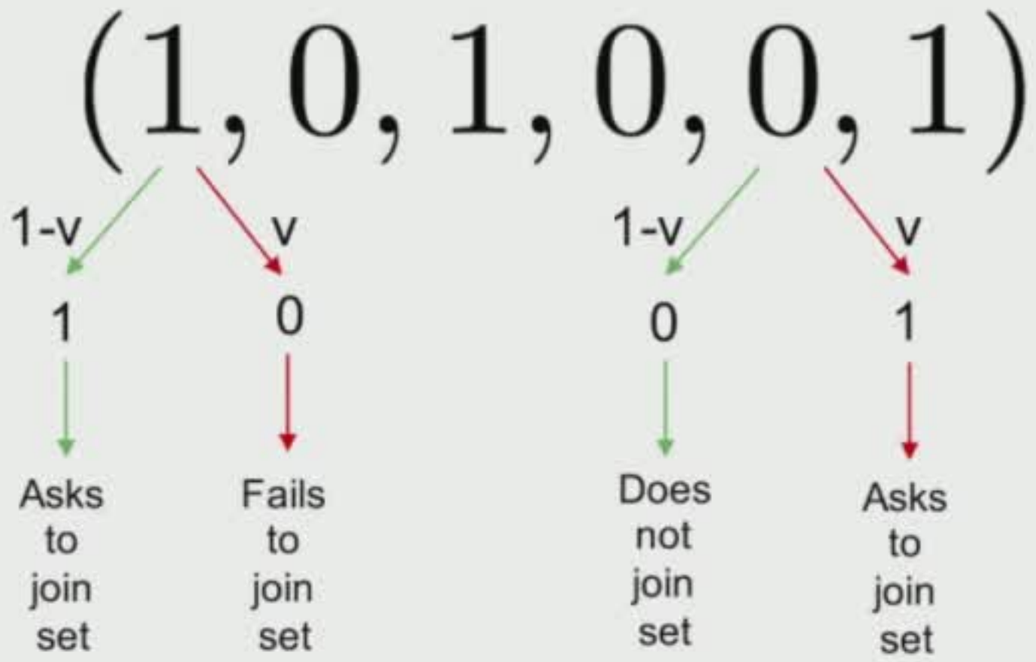
Hence, we refer to row i of matrix H as the vector $\vec{h}_i$: this vector gives the set memberships of individual i

Fitness of an individual

Fitness of individual i

$$f_i = 1 + \delta \underbrace{\sum_{j \neq i}}_{\star} \underbrace{(h_i \cdot h_j)}_{\star\star} \underbrace{(-cs_i + bs_j)}_{\star\star\star}$$

Group imitation & barriers to group entry



Parent's group memberships: 1 = in group, 0 = not in group

v = group "mutation" (exploration) rate

Barriers to group entry based on group size

Evolutionary set theory: imitation and group membership in the original model

- There were no barriers to group entry
  - Instead, include barriers to group entry (based on group size)
- Individuals imitated their parents' groups as a collection
  - Instead, imitate groups one group at a time, individually
- Individuals were required to be in K groups at all times
  - Instead, do not place any restrictions on the number of group memberships

Question: If we address these limitations, can we still see cooperation favored?

Conclusions

- When we impose realistic group entry rules, we find that cooperation can still be favored
- Cooperation is most favored when we allow for the existence of loners
- We also have analytical results for the special case of $M = 1$ set

Thank you!

Acknowledgments

Corina E. Tarnita

Vítor V. Vasconcelos

Tarnita Lab at Princeton

Funding

NIH NHGRI

NSF

GRFP