Evolutionary Game Theoretic and Multi-Agent System Models of the Emergence of Cross-Cultural Differences

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Cultural Classifications

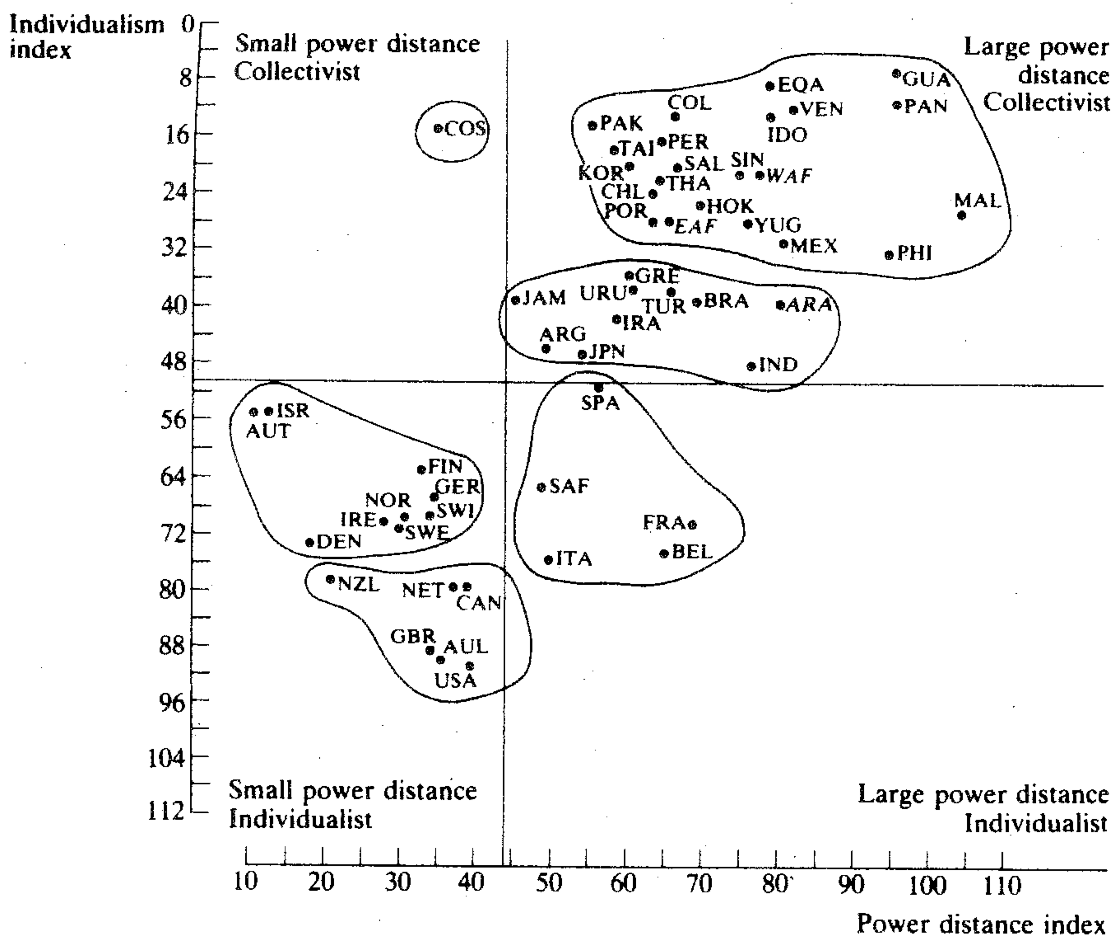
- Cultural Psychologists have developed various cultural scales
- "Tight" vs. "Loose"

Gelfand et al., Differences between tight and loose cultures: A 33-nation study. *Science,* 2011.

- "Collectivist" vs. "Individualist"

Hofstede, et al., *Cultures and organizations: Software of the mind*. Vol. 2. McGraw-Hill, 1991.

- These scales have correlations with various contextual factors and implications on behavior



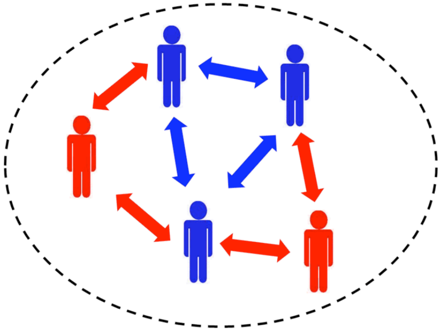
General Objective and Approach

Questions to Explore

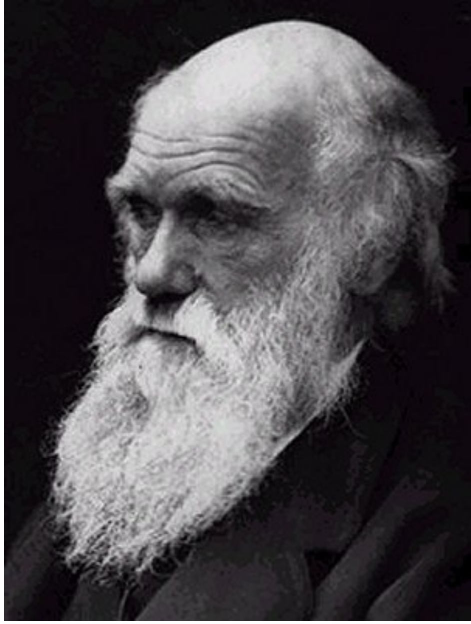
- Why do behavioral differences relating to cultural classification scales exist?
  - How do they emerge?
  - What factors lead to their emergence?

Approach

- Evolutionary game theoretic and multi-agent system models of
  - populations of interacting agents (social systems)
  - the evolution of behaviors therein (via cultural evolution or adaptation)



Evolution of behaviors?



Conditions for Natural Selection

1. Struggle for Existence (not all survive)
2. Variation (some more likely to survive)
3. Variation must be heritable

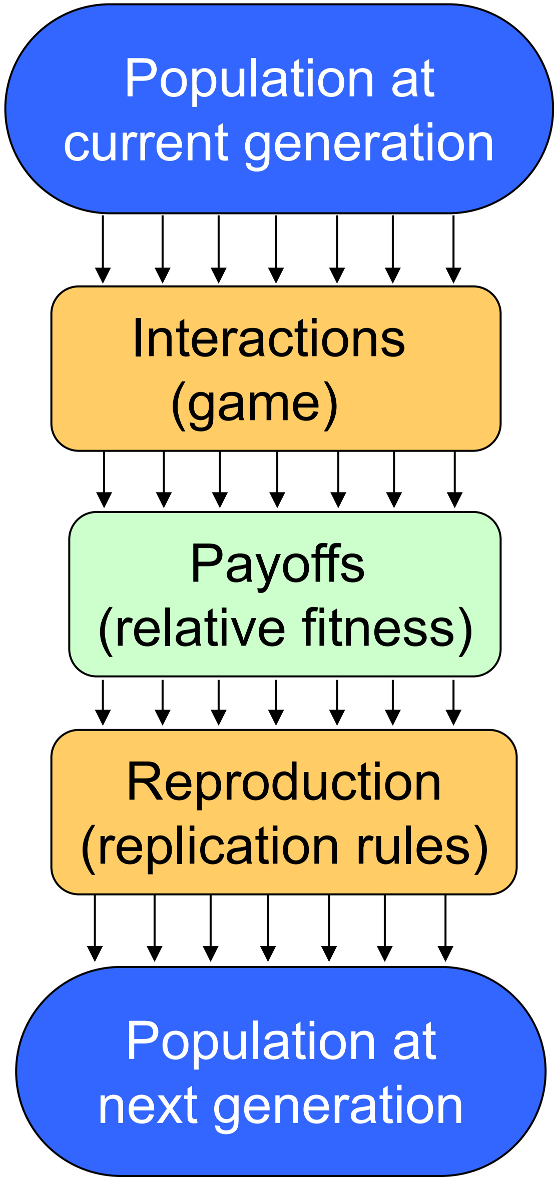
Cultural Adaptation

- Social learning and imitation is almost entirely unique to humans
- Cultural transmission allows rapid local adaptation
  - much faster than genetic adaptation

"Now, if some one man in a tribe, more sagacious than others, invented a new snare or weapon, …, the plainest self-interest, without the assistance of much reasoning power, would prompt the other members to imitate him;
and all would thus profit."
- Charles Darwin, *The Descent of Man* 1871, p. 155

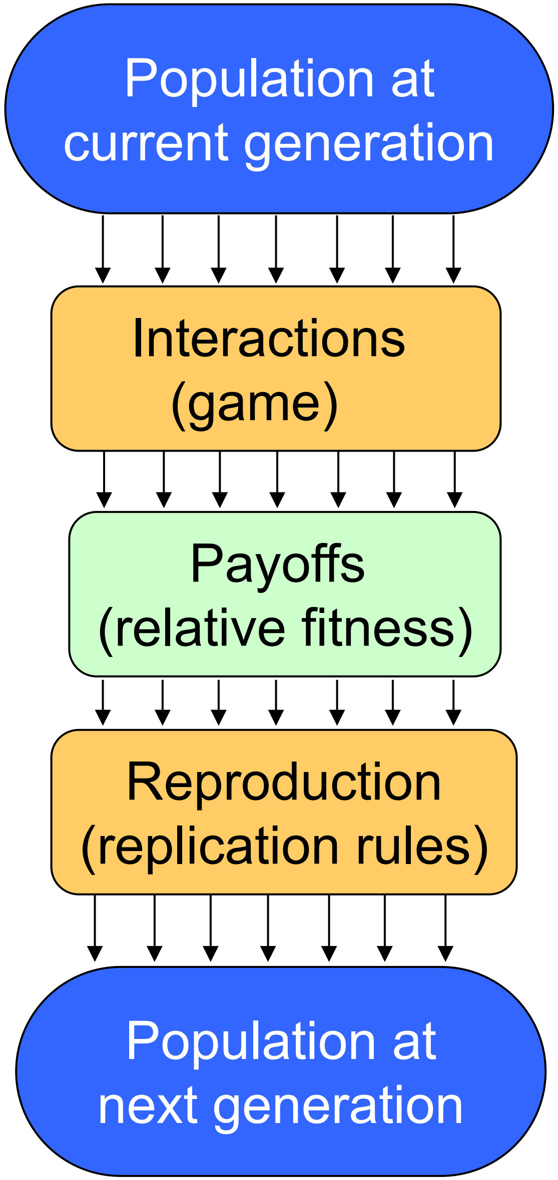
Evolutionary Game Theory (EGT)

- Application of Game Theory to populations that are evolving
  - J. Maynard Smith: The Logic of Animal Conflict, Nature 1973
- Population of individuals that use various strategies (➔ species)
- *Frequency-Dependent* Fitness
  - Fitness does not depend only on an agent's own strategy, but also on the strategies of other agents in the environment



EGT and Culture

- *Strategies* ➔ *Behaviors* to investigate
  - Success of behaviors depends on other behaviors in the population
- *Reproduction* ➔ *Cultural Transmission*
  - Humans learn from the successful
    - Social imitation often used as a guide in decision-making
    - Successful strategies have a higher probability of being adopted by others in the population
  - Random exploration of strategy space ➔ mutation



Phenomena Explored

1. **Punishment Propensities**
   - How likely people punish deviations from societal norms
2. **Third-Party Punishment**
   - Punishment on behalf of others as an uninvolved party
3. **Group-based/collectivistic vs. individualistic thinking**
   - Group environments with potential for conflict
   - Treat others through a group-entitative lens or treat them as individuals

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Punishment in Humans

- Humans are willing to punish norm-deviating behavior
  - At cost to self, even in one-shot games

Fehr 2000, Fehr 2002, Fehr 2003, Ostrom 1994, Price 2002, Hammerstein 2003, De Quervain 2004, Nakamaru 2006, Camerere 2006

- Punishment can be important in the emergence and maintenance of cooperation in societies
  - Can establish and maintain cooperative norms in collective action and cooperation games

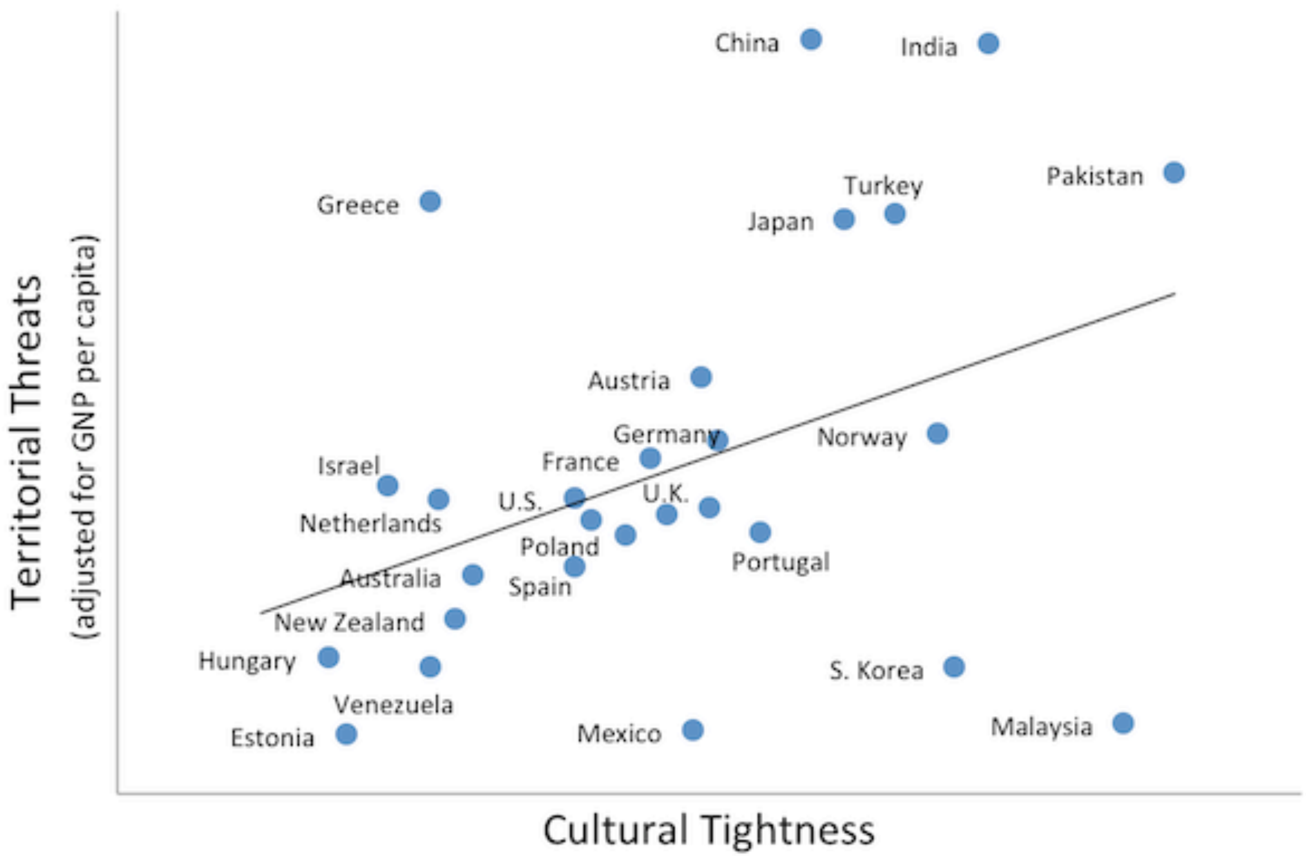
Boehm 1993, Boyd 1992, Henrich 2001, Hauert 2002, Henrich 2006, Boyd 2003, Brandt 2003, Brandt 2006, Hauert 2007

- Different cultures have different propensities to punish deviations from norm
  - "Tight" cultures: more likely to punish
  - "Loose" cultures: less likely to punish

Gelfand et al. 2011

Punishment and Societal Threat

- Exposure to external societal threat to correlate with a culture's tightness *Gelfand et al. 2011*
  - external man-made threat
  - ecological disasters and threats to group resources



Punishment Propensities: Objectives and Approach

Questions to Explore

- Can the degree of threat to a society explain differences in punishment propensities?
  - Is there support for a causal relationship?

Approach

- Evolutionary Game Model
  - agents interact in a *Public Goods Game* with punishment
  - Include different degrees and operationalizations of threats
    - > Explore effect on punishment, group survival, evolutionary dynamics and stability

Public Goods Game (PGG)

- Paradigm to study cooperation and norm violation *Henrich 2001, Hauert 2002, Brandt 2003, Henrich 2004, Brandt 2006, Traulsen 2009, Hauert 2010*
- Mutiplayer game, N players play the PGG
  - Each player may contribute an amount c
  - ***Cooperator:*** contributes
  - ***Defector:*** doesn't contribute

- The sum of all contributions is multiplied by a factor $r > 1$ and distributed equally among everyone
- Tempting to defect, because it avoids contribution cost c
- Societal breakdown: evolve to nearly* 100% defectors
  - Payoff for all individuals is near 0
- Use punishment to deter defection

Punishment in the PGG

At each generation:

1. Contribution Phase
   - *Cooperate* or *Defect*
2. Punishment Phase:
   - Opportunity to punish Defectors
     - Cost is λ
     - Reduces Defector's payoff by an amount $\rho > \lambda$

$-\lambda$

$-\rho$

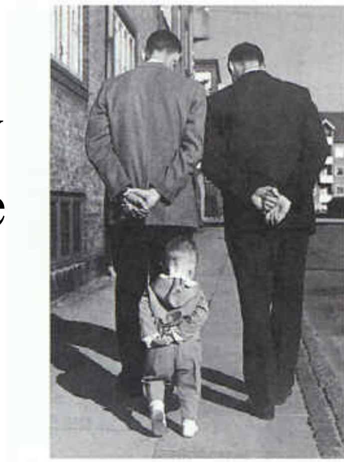
Basic Evolutionary PGG Model with Punishment

- Two basic strategies available to agents:
  - *Cooperator (C)*
  - *Defector (D)*
- *Punishment Propensity* ***q*** *:*
  - Each Cooperator has a probability ***q*** of punishing a Defector when given the chance
  - By varying ***q***, we can observe effect on evolutionary dynamics, group payoff, and group survival
- After *Contribution Phase* and *Punishment Phase*, agents reproduce into the next generation according to the *Replicator Dynamics*

Replicator Dynamic

- Origins in modeling growth of animal populations

- At generation t, let
  p_t = proportion of a agents in population
- At generation $t+1$,
  the proportion of a agents is:
  $p_{t+1} = p_t\,(\pi(a)\,/\,\theta)$
  - $\pi(a)$ = expected payoff for a agents
  - θ = expected payoff of entire population



- A strategy's numbers grow or shrink proportionately to how much better or worse it does than the average
- Social learning analogy: imitate others at rate proportional to how much better they are

ODE version: $\dot{x}_i = x_i\,[\,\pi_i(x) - \theta(x)\,], \quad \theta(x) = \sum_i x_i\,\pi_i(x),$

Basic Payoffs in our PGG

- From the definitions of the previous slides, it follows that:
- Expected Payoff to Defectors:

$$
\begin{aligned}
\pi_D &= \sum_{k=0}^{N-1} \left(\frac{r}{N}k - k\,q\,\rho\right) x_C^k\, x_D^{N-1-k} \binom{N-1}{k} \\
&= \left(\frac{r}{N} - q\,\rho\right)(N-1)\,x_C
\end{aligned}
$$

- Expected Payoff to Cooperators:

$$
\begin{aligned}
\pi_C &= -c + \sum_{k=0}^{N-1} \left[\frac{r}{N}(k+1) - q\,\lambda\,(N-k-1)\right] x_C^k\, x_D^{N-1-k} \binom{N-1}{k} \\
&= r x_C + \frac{r x_D}{N} - c - q\lambda(N-1)x_D
\end{aligned}
$$

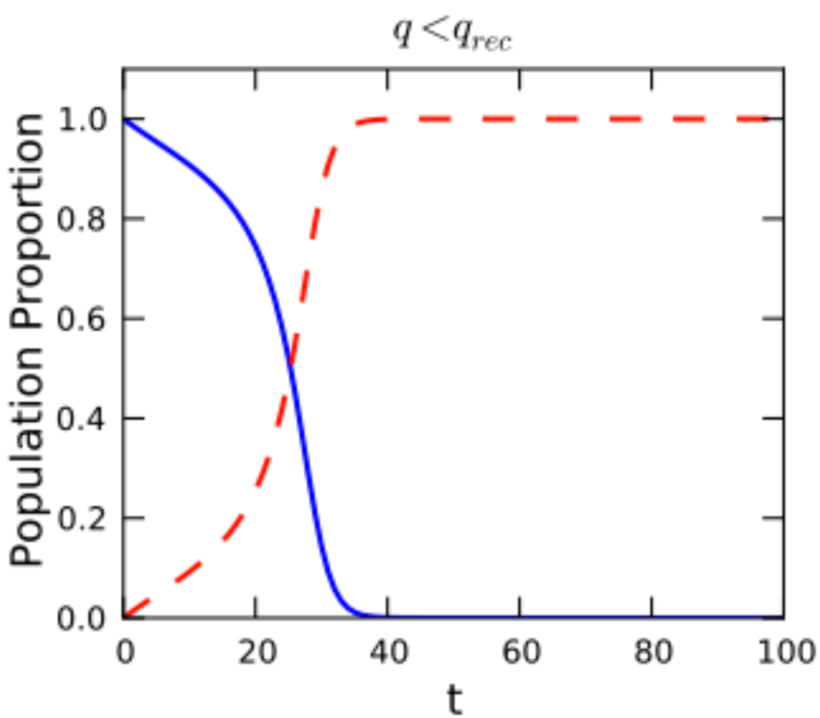
Basic Population Dynamics

Solve Replicator Dynamics (ODE Version)

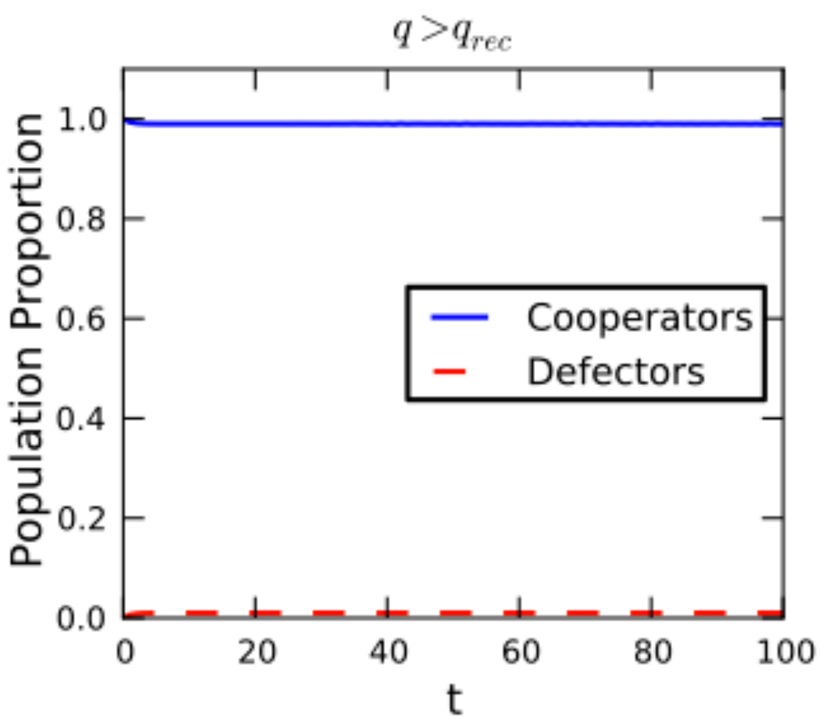
$$\dot{x}_i = x_i \left[\pi_i(x) - \theta(x) \right], \quad \theta(x) = \sum_i x_i \, \pi_i(x),$$

There exists a value for the minimum punishment propensity required to withstand Defectors. Call this value q_{rec} .

Low Punishment Propensity



High Punishment Propensity



Types of External Societal Threat

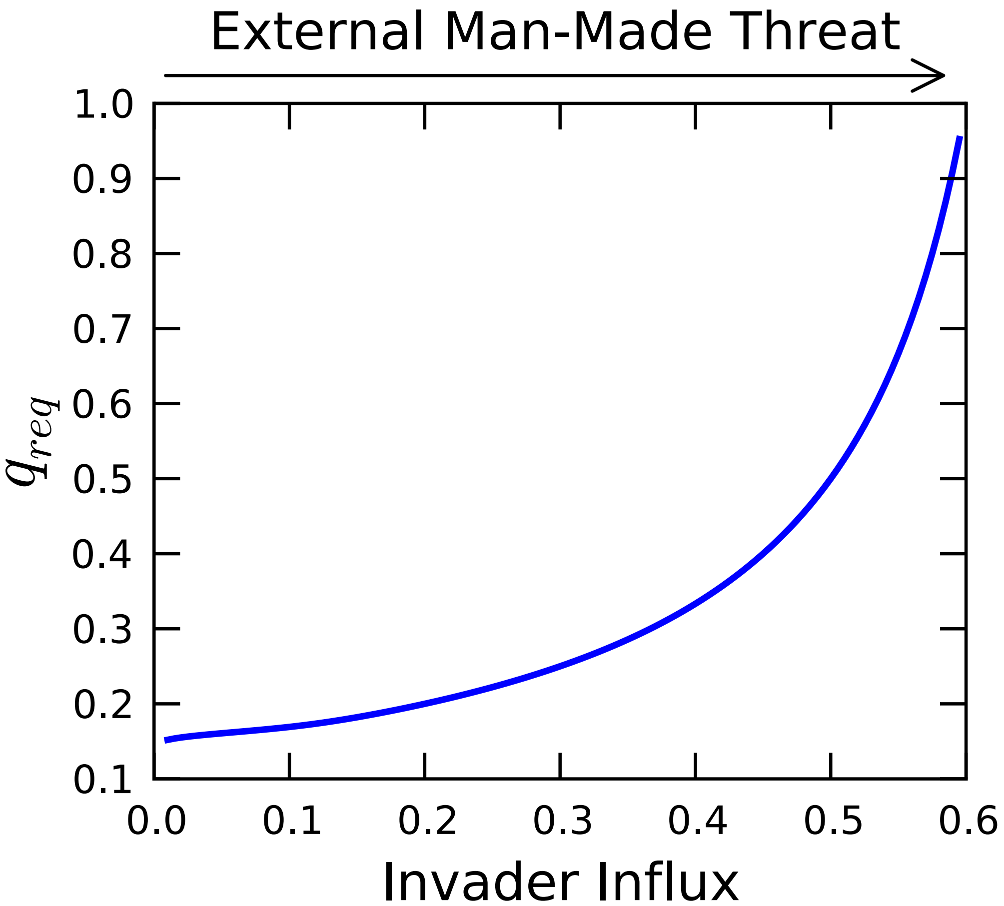
1. External man-made threat (warfare, competition for resources)
2. Ecological threats like natural disasters and diseases

How to implement these in EGT model:

a) An influx of Defectors in the population
b) A decrease in the overall payoff created by the population (decrease ***r***)

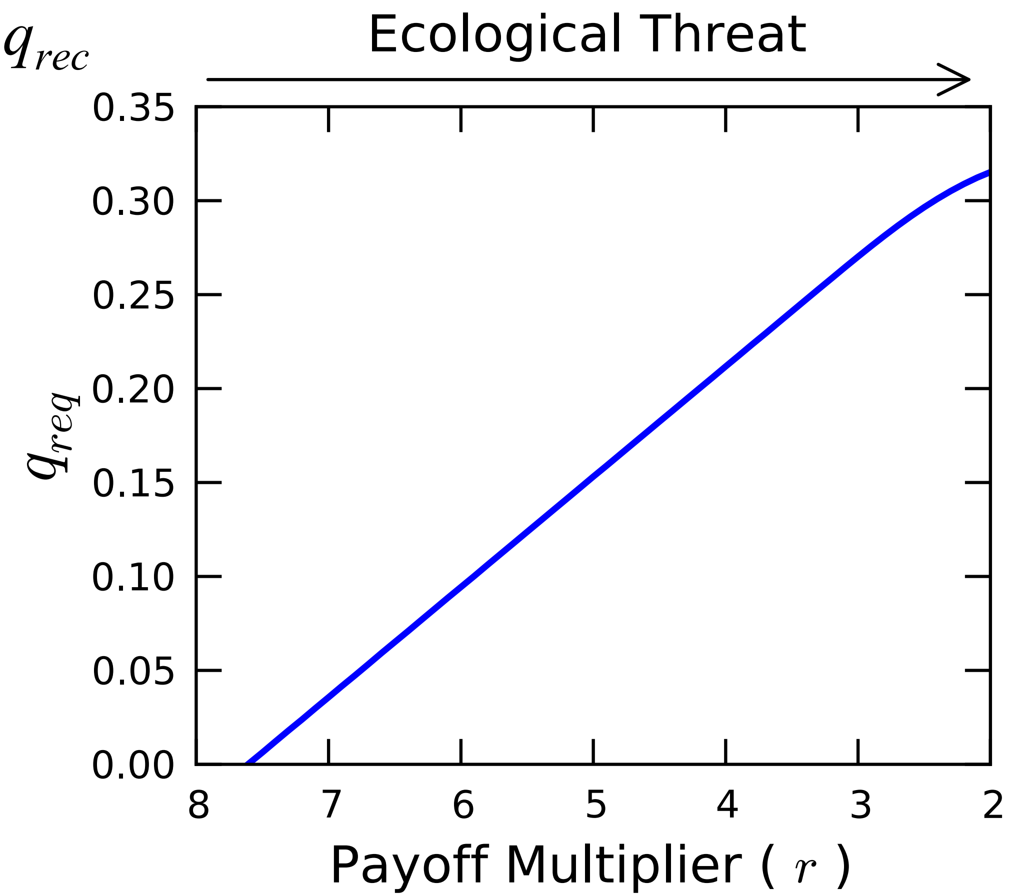
External Man-made Threat Increases q_{req}

- Analytical results, solving $\dot{x}_i = x_i \left[\pi_i(x) - \theta(x) \right], \quad \theta(x) = \sum_i x_i \pi_i(x),$ for q_{rec} under different levels of invader influx
- Higher threat ➔ Higher q_{rec}
  - i.e, more punishment is needed to prevent breakdown into defection



Ecological Threats

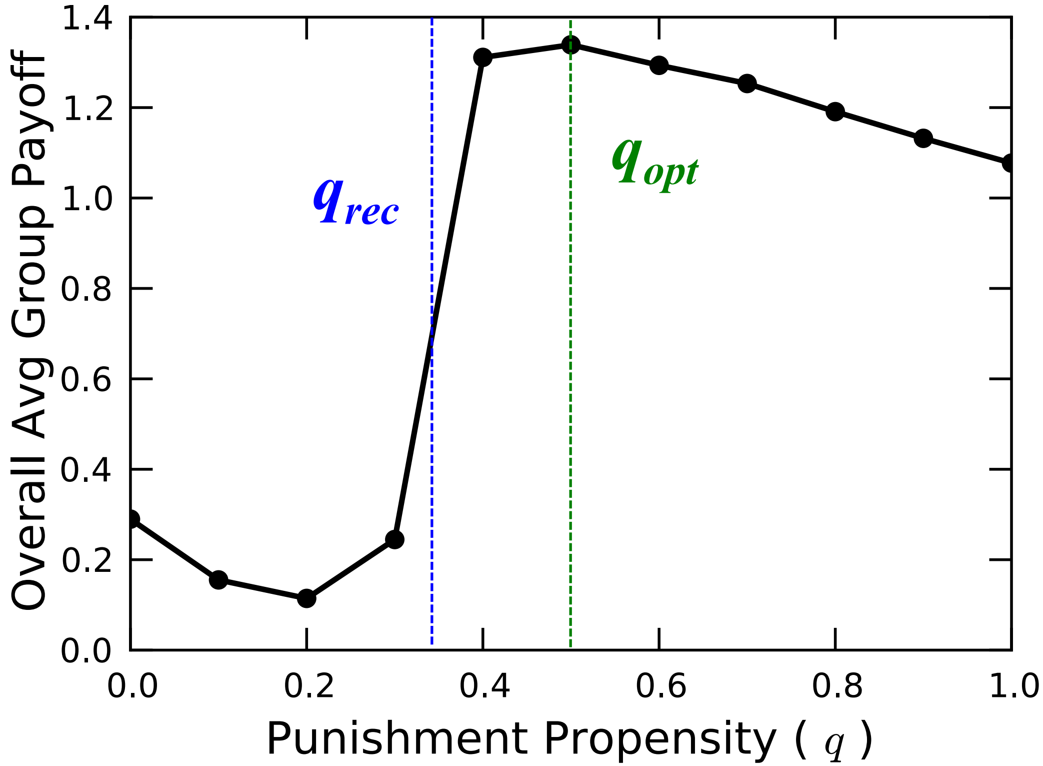
- Analytical results, solving $\dot{x}_i = x_i\,[\,\pi_i(x) - \theta(x)\,], \quad \theta(x) = \sum_i x_i\,\pi_i(x),$ for q_{rec} under different ***r*** (overall payoff)
- Higher degree of threat ➔ Greater decrease in ***r***
- Higher threat ➔ to higher q_{rec}
  - i.e, more punishment is needed to prevent breakdown into defection



Too Much Punishment?

- So far we have shown: increased threats increase punishment propensity required (q_{req}) to withstand societal breakdown
- There is an optimal punishment propensity $q_{opt} > q_{rec}$
  - Punishment above q_{opt} can harm overall population payoff

➔ Excess punishment is selected against under group selection



Group Selection

- Selection occurs between groups (societies) of individuals as well as between individuals within groups
- Mechanisms: Indirect competition for resources, Direct competition (warfare), Selective migration and assimilation, Inter-group imitation of the successful
- Groups with higher payoff have an *evolutionary advantage*

Group Selection

- Can select between multiple stable equilibria
- Example: Stag Hunt
  - the probability that a *Stag* player will get 8 rather than 0 depends on the proportion of other *Stag* players in the group
- If a group consists of all *Hare* players, playing *Hare* is stable
- If a group consists of all *Stag* players, playing *Stag* is stable

Stag Hunt

Hunter 2 / *Hunter 1*	Stag (risky)	Hare (safe)
Stag (risky)	8, 8	0, 4
Hare (safe)	4, 0	4, 4

Nash equilibria

BUT:

Groups at the Stag equilibria achieve much higher payoff than groups at the Hare equilibria and are thus selected for under group selective pressures!

Punishment and Threat: Conclusions

- Explored the relationship between punishment propensity and societal threat
- Increased societal threat increases punishment required ($\boldsymbol{q_{req}}$)
- Punishment propensity above $\boldsymbol{q_{opt}}$ harms group payoff
- Groups that are to survive under different threat conditions require different $\boldsymbol{q}$

Limitation:

- Did NOT answer how this $\boldsymbol{q}$ can evolve within a society without group selection
  - In order to do this, we need a more detailed model

Hilbe and Traulsen Model

Hilbe & Traulsen, *Emergence of responsible sanctions without second order free riders, antisocial punishment or spite*. Scientific Reports 2012.

- Includes a way to model others' reputation for punishing
  - Information level $i = P(\textit{know whether others will punish you})$

  → Much larger collection of strategies

  4 Strategies for Contribution Phase

  x 4 Strategies for Punishment Phase

  = 16 Strategies

- A stable amount of punishers and non-punishers (punishment propensity) evolve within a population

Hilbe and Traulsen Model Strategy Set

Strategies for Contribution Phase

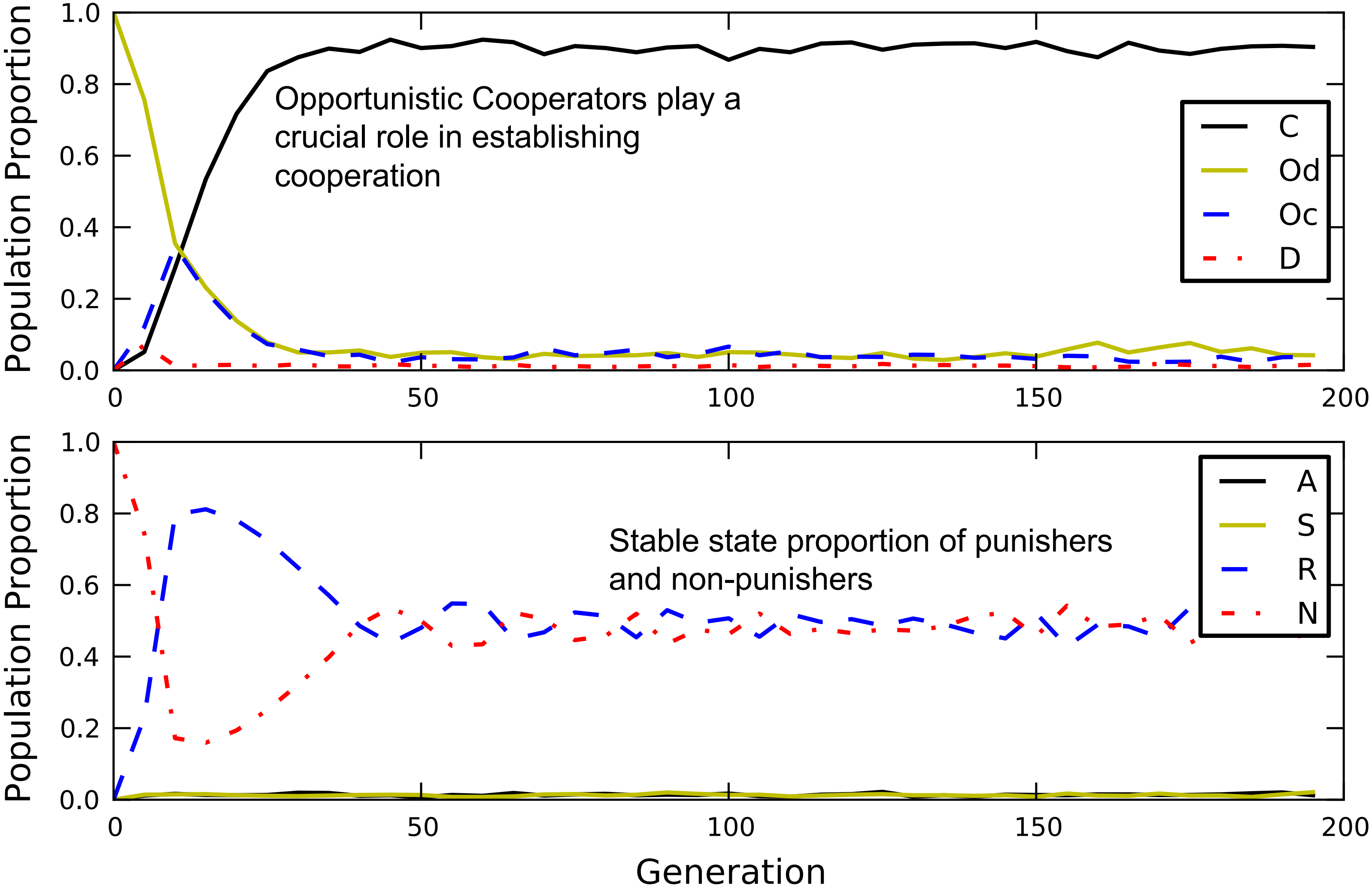
Hilbe & Traulsen, Science 2012

Label	*Name*	*Description*
C	Cooperator	Always contributes.
D	Defector	Never contributes.
Oc	Opportunistic Cooperator	Cooperates unless it knows that it is beneficial to defect based on punishment reputation of co-players.
Od	Opportunistic Defector	Defects unless it knows that it is beneficial to cooperate based on punishment reputation of co-players.

Strategies for Punishment Phase

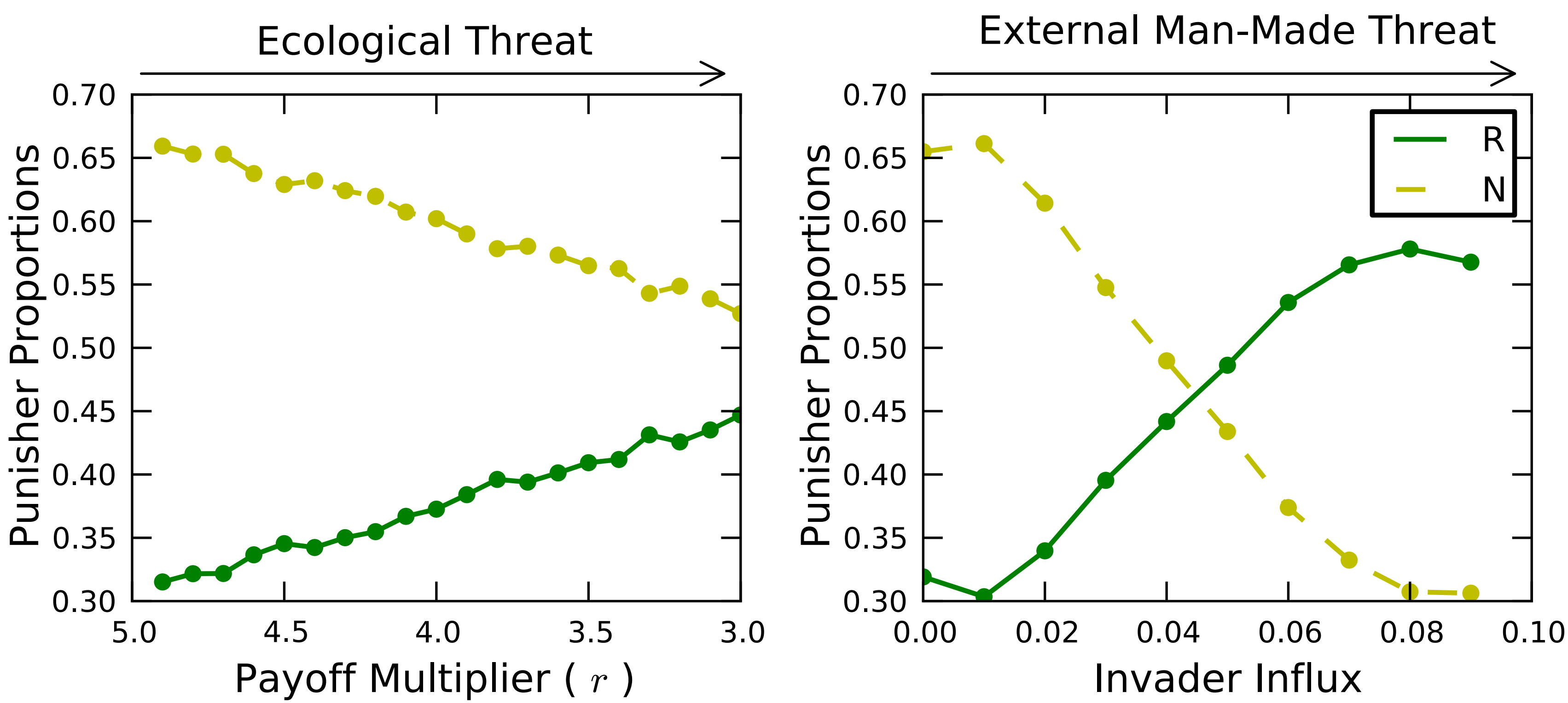
Label	*Name*	*Description*
R	Responsible Punisher	Punishes defecting players.
S	Spiteful Punisher	Punishes everyone.
A	Antisocial Punisher	Punishes cooperating players.
N	Non-Punisher	Punishes no one.

Example Dynamics



Effect of Threats on Stable Punisher Proportion

- How much punishment is stable depends on threat amount
- Again, more threat leads to to higher punishment propensity



Punishment and Threat: Conclusions

- Tested the relationship between punishment and societal threat
- Provided a partial explanatory model of difference in Tight vs. Loose cultures
- Results support a causal relationship between otherwise purely correlational data

Cultures' punishment propensities are a function of the degree of societal threat to which cultures are exposed.

Phenomena Explored

1. **Punishment Propensities**
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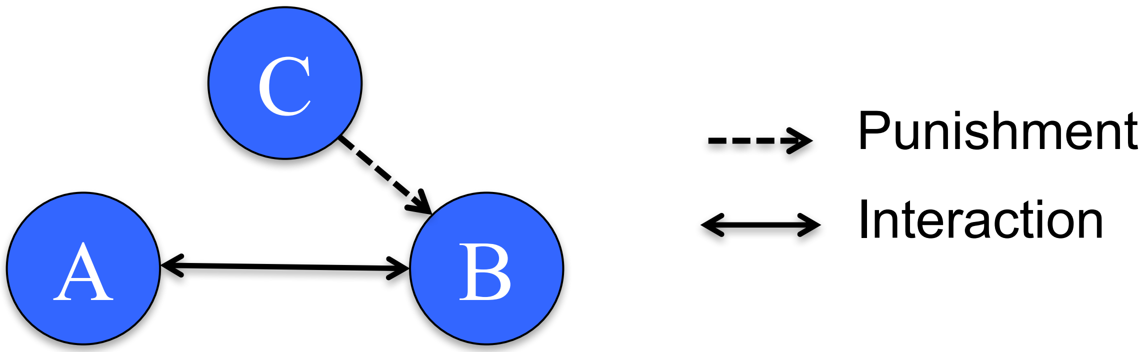
Third-Party Punishment (3PP)

- Punishment in the role of an uninvolved third party, on behalf of someone else



- Empirical evidence that humans (and some animals) do engage in 3PP exists

  Fehr 2003, 2004; Raihani,2010.

- But, other empirical studies have also found 3PP to not occur in humans

  Pederson 2013.

3PP: Objectives and Approach

Basic Questions

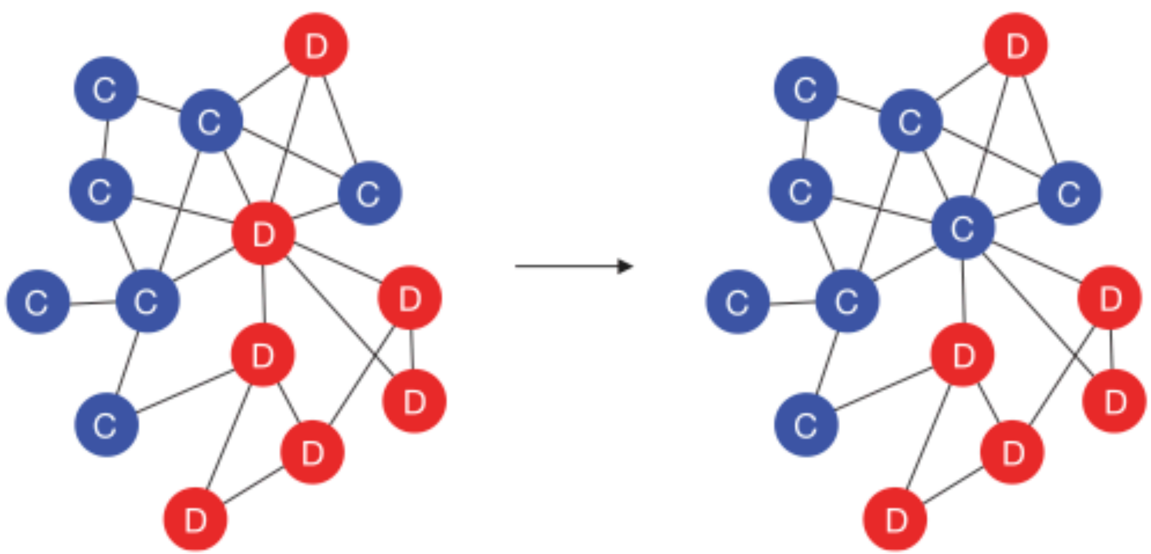
- What conditions foster the existence of 3PP?
- How do the dynamics of 3PP relate to *characteristics of collectivist/individualist* cultures?
  - Strength-of-(social)-ties (high in collectivist cultures)
  - Mobility (low in collectivist cultures)

Approach

- Same Evolutionary Game Model as before, but
  - population structure
  - allow the possibility of 3PP (pair agents randomly for punishment)
- Explore the evolution of 3PP under different conditions

Games with Population Structure

- Populations are structured on a graph
  - Agents positioned on nodes
  - Edges represent social connections
    (possibilities for interaction and imitation/social learning)



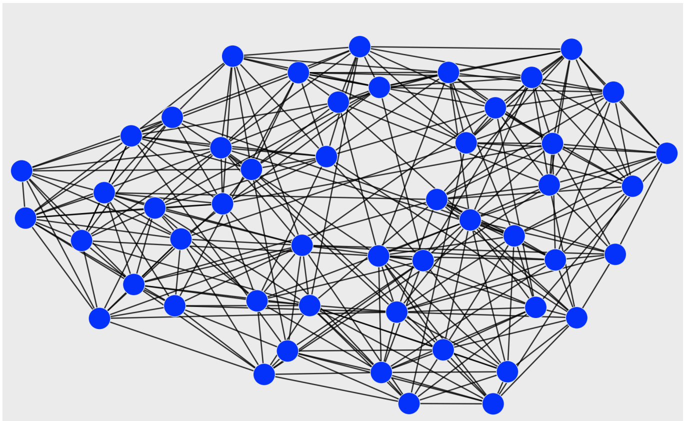
* Figure from Ohtsuki et al. 2006

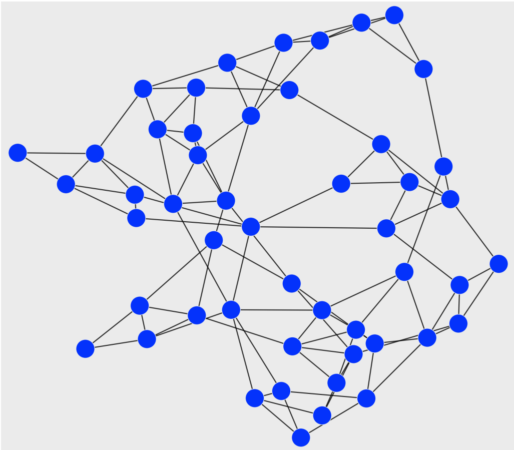
Strength-of-Ties

- T*ie strength* between humans is measured in terms of how often agents interact with each other during a period of time.

  Granovetter 1983 The strength of weak ties: A network theory revisited. *Sociological Theory*, 1(1), 201–233.

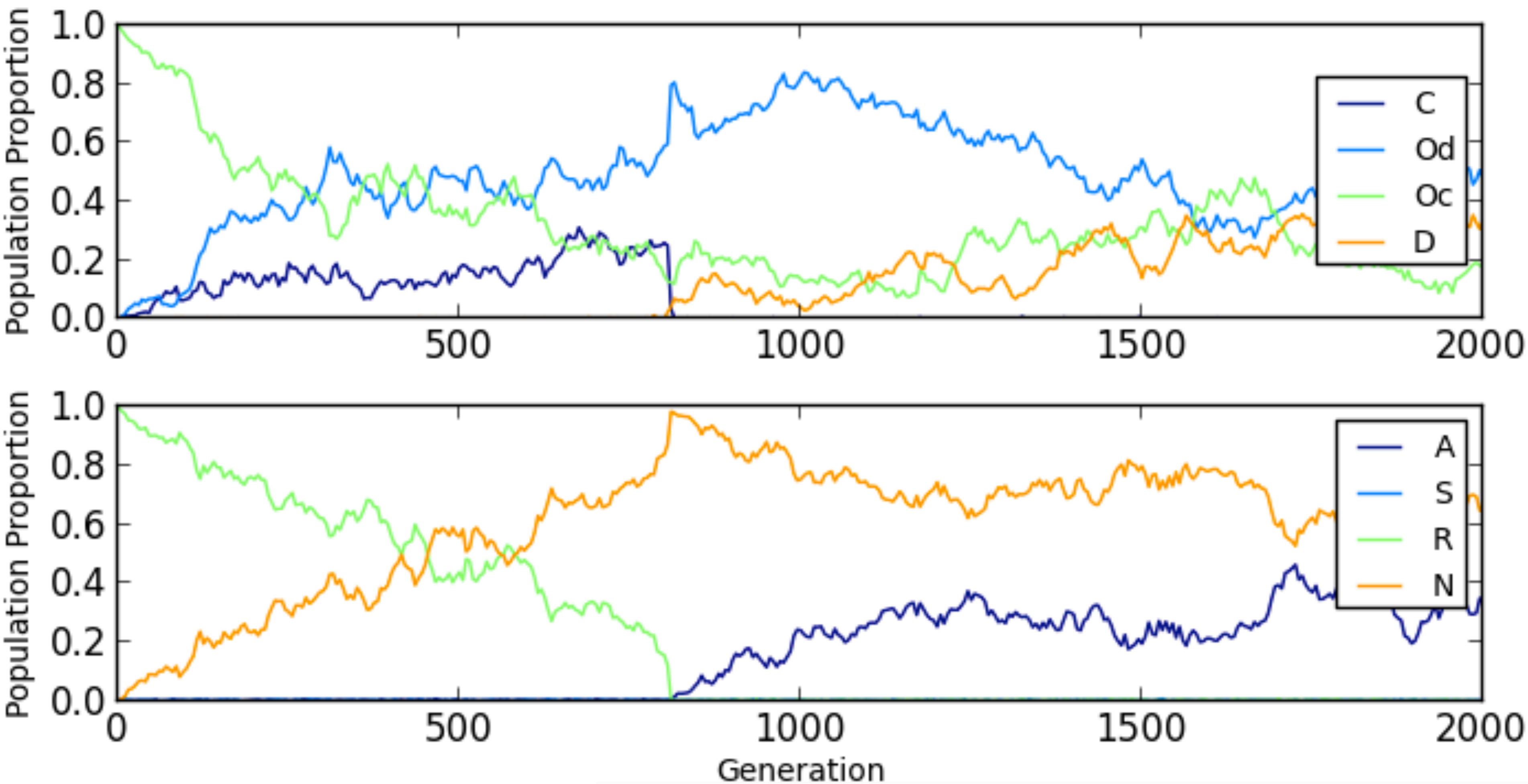
- Thus, if agents interact with their neighbors and have an equal number of interactions per time period
  - high degree nodes ➔ high strength-of-ties
  - low degree nodes ➔ low strength-of-ties





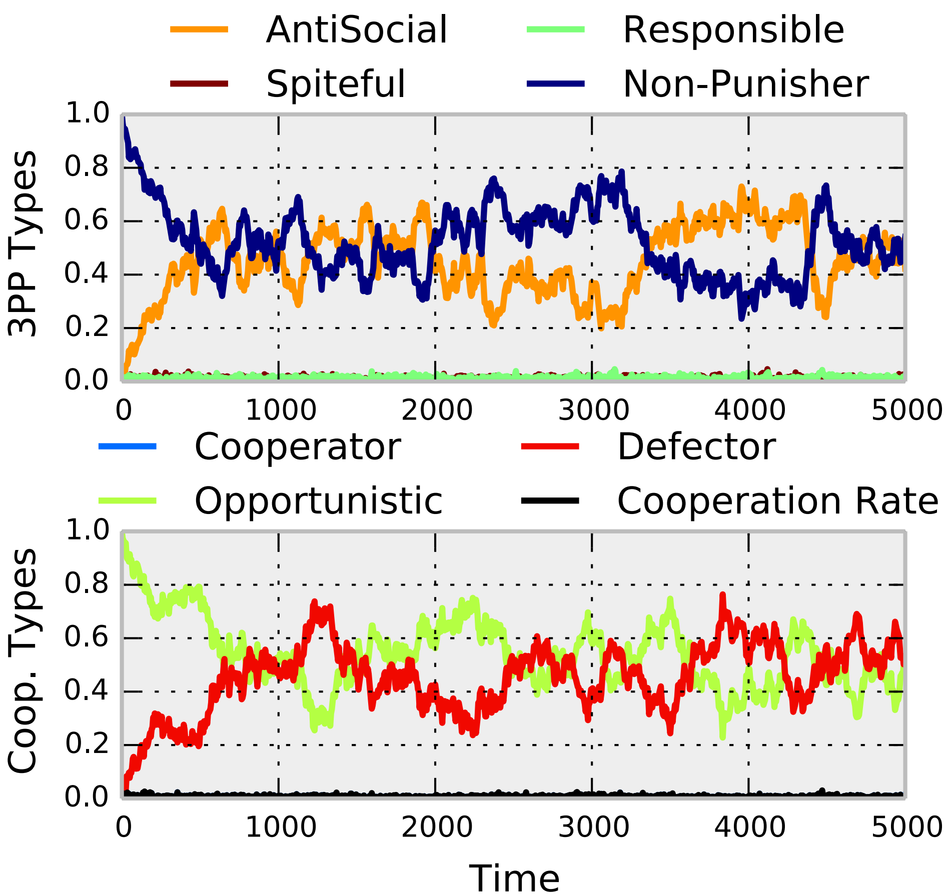
Difficult for 3PP to Evolve

Well Mixed Population (i.e. Fully Connected Graph, No Population Structure)

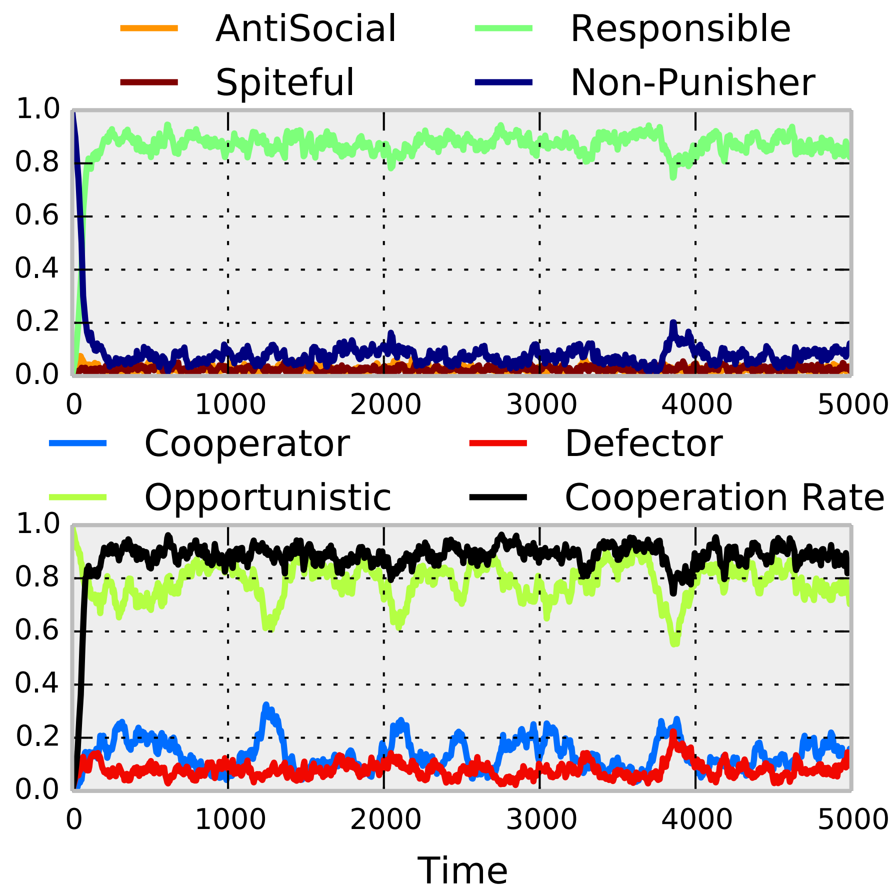


High Strength-of-Ties Enable the Evolution of 3PP

Low Strength-of-Ties

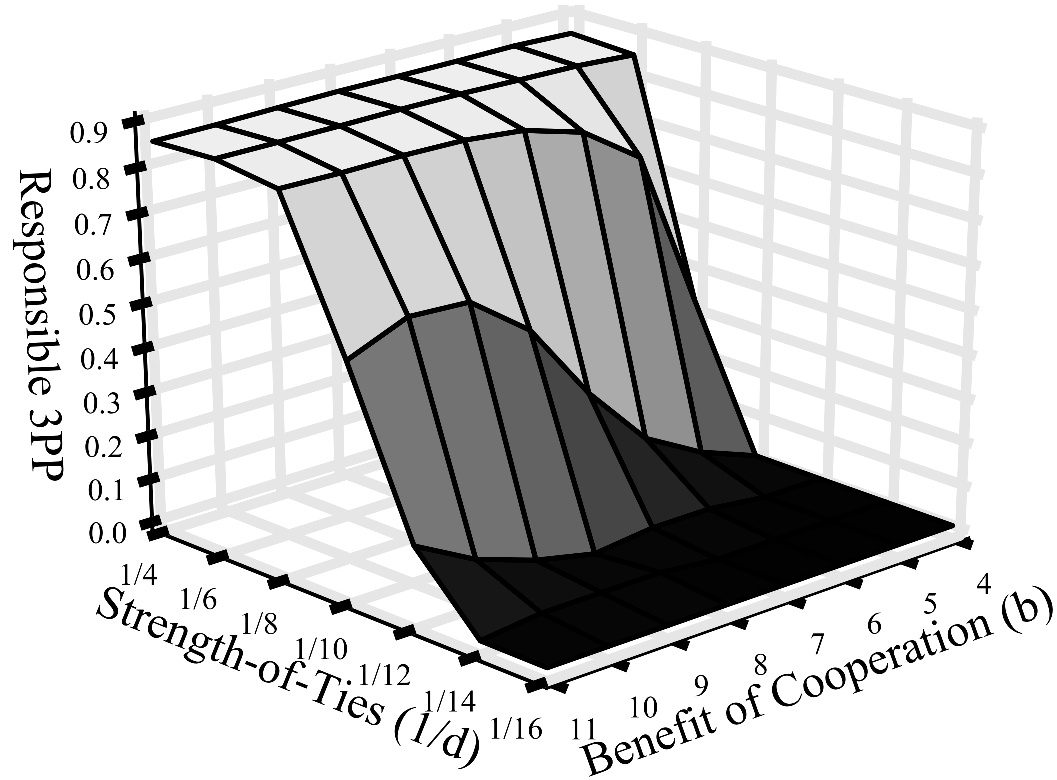


High Strength-of-Ties

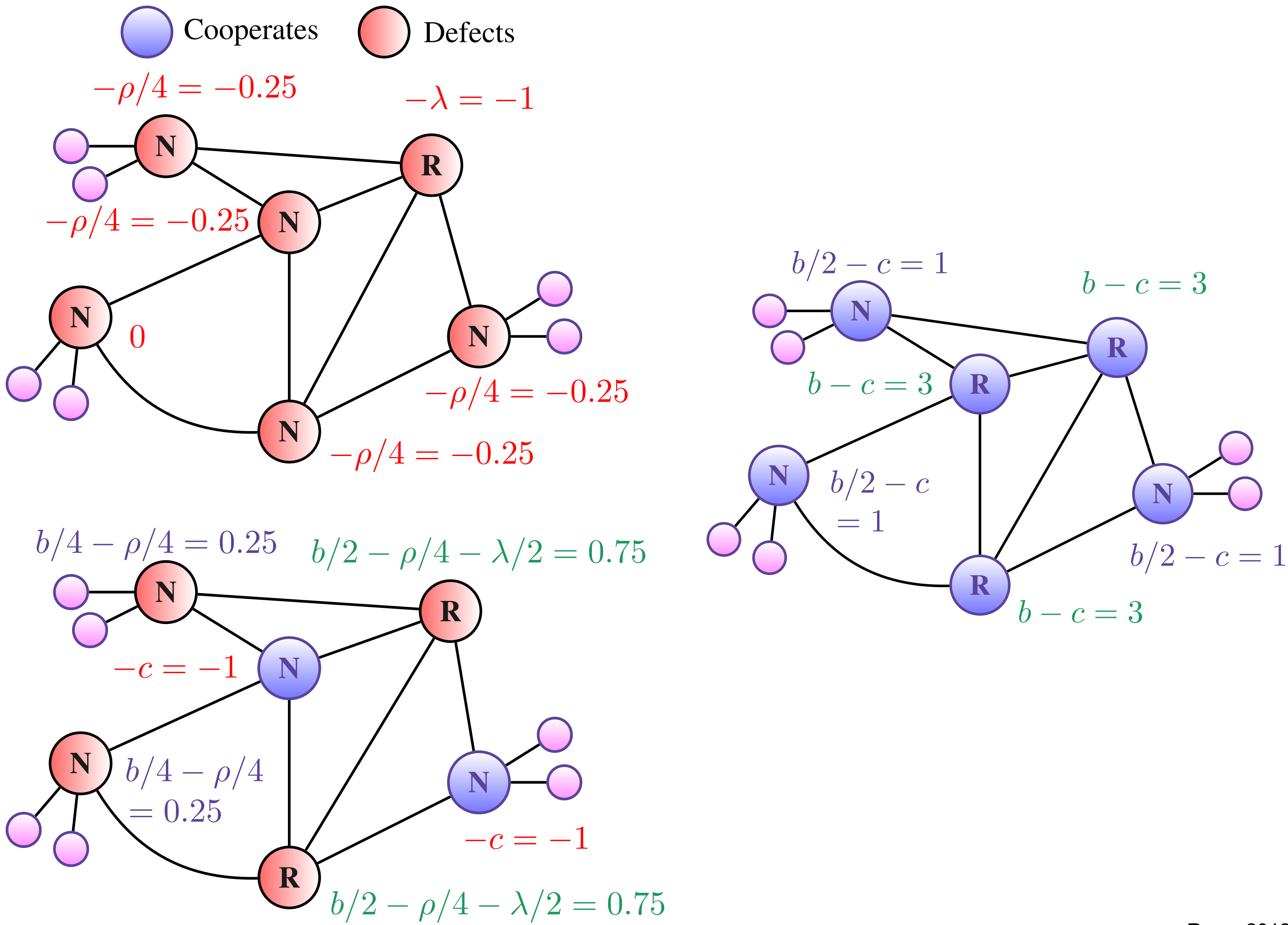


High Strength-of-Ties Enable the Evolution of 3PP

a) Varying Strength-of-Ties



Effects of Responsible 3PP on Local Cooperation



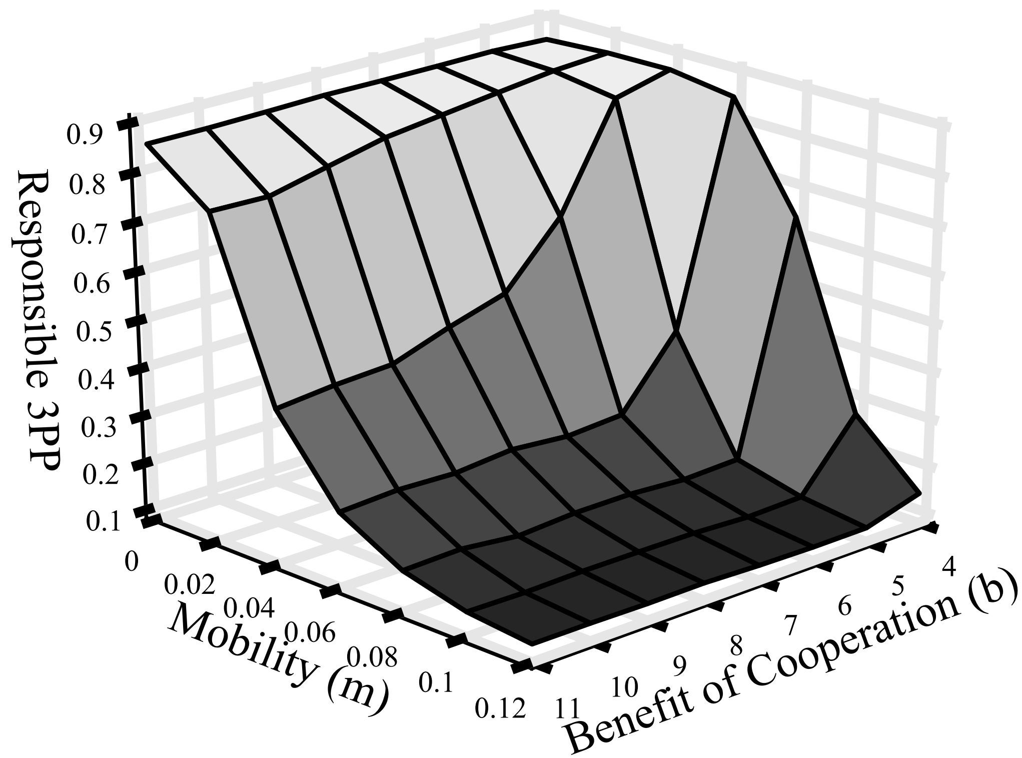
Mobility

- degree to which humans change their location, and, as a result, their position within the social network within a population
- *Individualistic* cultures tend to have very high mobility, people can easily exit their social group
- *Collectivistic* cultures tend to have low mobility, people are are less able to easily exit their social group
- In mobile populations, humans may change their location for a multitude of reasons
    - mobility = a *probability m* with which each agent switches position with a randomly chosen other agent each generation

Evolution of 3PP Requires Low Mobility

- With higher mobility, 3PP agents are less likely to cluster and induce local cooperation, and thus are less likely to spread

b) Varying Mobility



Evolution of 3PP: Conclusions

- Evolution of 3PP requires high societal constraint
  - High *Strength-of-Ties*
  - Low *Mobility*
  - Both tend to be the case in "collectivist" cultures
- 3PP cannot be sustained or uphold cooperation in low societal constraint environments
  - Other mechanisms needed for the evolution of cooperation in such environments
  - Open question: What are they?

Phenomena Explored

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Group-entitative vs. individualistic thinking

- Agents in collectivistic environments think *group-entitative*
    - actions of individuals belonging to group viewed interchangeably with action of group

Basic Questions

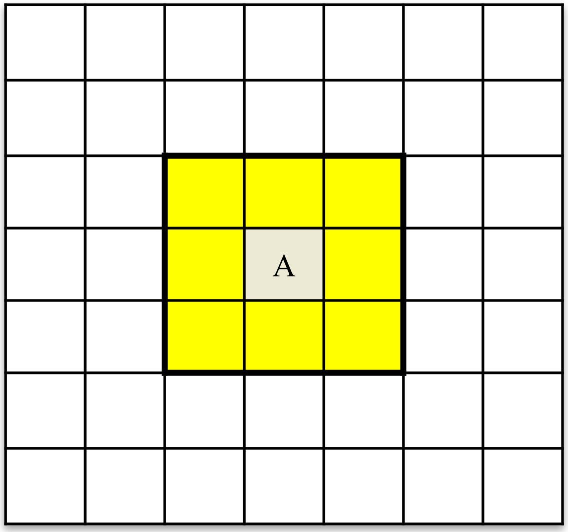
- How does group entitativity affect cooperation and conflict?
- Under what conditions does group-entitative vs individualistic thinking evolve?

Approach

- EGT model of agents belonging to groups
    - Agents interact in cooperation game
- Agents can either be group-entitative or individualistic

Group Model Details

- Agents interact in a cooperation game on a spatial grid
- Each agent has an observable *group tag* that designates the group it belongs to
- Agents reproduce into neighboring locations based on payoff
- Agents die off at a certain rate
- *Individualistic* agents:
  - Decide whether to cooperate or not based on partner's last action against self
- *Group-Entitative* agents:
  - Decide whether to cooperate or not based on the last action of anyone in partner's group against self



Results

- Group Entitative agents evolve to the majority
- Group Entitative agents evolve in-group biased strategies
  - Cooperate with in-group members
  - Defect against out-group members

  ➔ Group conflict evolves

BUT: Under increased mobility (agents move around on grid)

- Individualistic agents evolve to take over the population
- Individualistic agents evolve to play Tit-for-Tat strategy

  ➔ Higher overall rate of cooperation evolves

Conclusions Summary

1. **Punishment Propensities**

Cultures' punishment propensities are a function of the degree of societal threat to which cultures are exposed.

1. **Third-Party Punishment**

High strength-of-ties and low mobility enable/are required for the evolution of responsible 3PP.

1. **Group-based/collectivistic vs. individualistic thinking**

Group-entitative, group-biased behavior, and inter-group conflict easily evolves in group environments. High mobility however leads to individualistic thinking and can lead to higher rates of cooperation.

Conclusions

- Population-level differences in cultural phenomena can emerge from individual-level interactions and adaptation due to different contextual factors
- EGT and MAS models of social systems can:
  - Provide explicit, dynamic, explanatory models of evolution of cultural differences
  - Help establish support for causal relationships that are often difficult or impossible to test empirically
  - Help promote cross-cultural understanding by showing how cultural differences, which may appear puzzling, can be adaptive to societies' ecological and historical contexts
- Presented models lay the foundation for more complex and ultimately predictive tools of behaviors in human populations

16 Reasons to Model *other than* Prediction

J. Epstein, JASSS 2008

1. Explain (very distinct from predict)
2. Guide data collection
3. Illuminate core dynamics
4. Suggest dynamical analogies
5. Discover new questions
6. Promote a scientific habit of mind
7. Bound (bracket) outcomes to plausible ranges
8. Illuminate core uncertainties
9. Offer crisis options in near-real time
10. Demonstrate tradeoffs / suggest efficiencies
11. Challenge the robustness of prevailing theory through perturbations
12. Expose prevailing wisdom as incompatible with available data
13. Train practitioners
14. Discipline the policy dialogue
15. Educate the general public
16. Reveal the apparently simple (complex) to be complex (simple)