Evolution of Cooperation

Among "Boundedly Rational" Artificial Agents

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About Me

PhD in Computer Engineering, 2017

- Boğaziçi University
- Area of research: Complex Systems

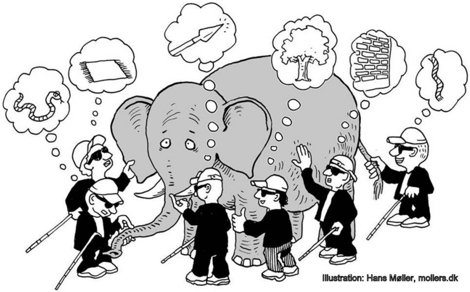
MS in Artificial Intelligence, 2009

- Pierre-et-Marie Curie University (Paris VI)

BS in Computer Engineering, 2007

- Galatasaray University

Outline



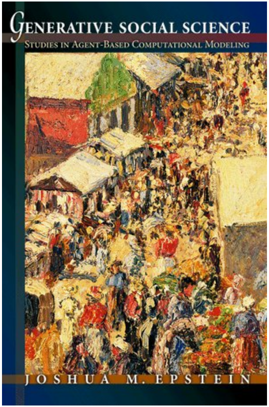
The parable of the blind men and the elephant

Agent-Based Modeling (ABM)

ABM perspective

ABM provides us a new way of thinking perspective (model) on how emergent higher order features "grow" from bottom-up.

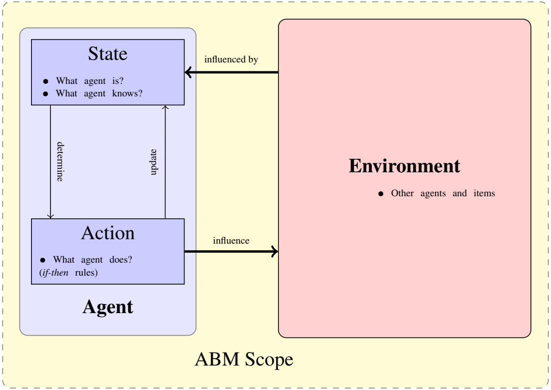
Complex social patterns can arise as a result of simple local rules.



ABM resembles French impressionist paintings.

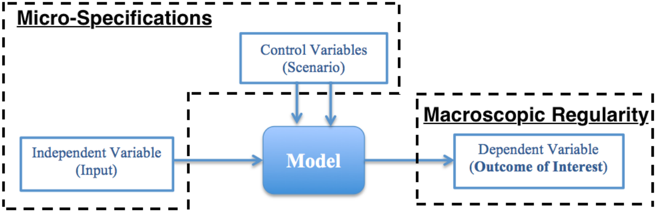
An Agent

is an *autonomous* computational unit



Generative Social Science

Are the given microspecifications sufficient to generate a macrostructure of interest?



Micro-to-macro mapping

We get macro-surprises despite complete micro-knowledge.

Cooperation is a Dilemma

How selfish beings manage to cooperate?

The construction of new features requires the cooperation of simpler parts

- replicating molecules $\rightarrow$ cells
- cells $\rightarrow$ organisms
- organisms $\rightarrow$ groups
- groups $\rightarrow$ societies, culture, civilisations

Darwin noted cooperation as a potential problem to his theory

Cooperative behavior involves a cost for the individual. It does not favor reproductive success.

Prisoners Dilemma Game

Rationality

Assuming that the other will cooperate, it is best for you to defect($T > R$). Assuming that the other will defect, it is best for you to defect($P > S$).

Dilemma

- (Individual) Rationality leads to defection.
- Mutual cooperation is better than mutual defection.

	C	D
C	R = 3	S = 0
D	T = 5	P = 1

Conditions:

- $S < P < R < T$
- $S + T < 2R$

Threat Game [1]

Co-evolution of Memory and Cooperation

What is the effect of increasing level of threat on the co-evolutinary dynamics of memory and cooperation?

[1] Uzay Cetin and Haluk O. Bingol, The Dose of the Threat Makes the Resistance for Cooperation, *Advances in Complex Systems* (accepted), 2017

Model

A population of N agents, who have limited memory size M, will play Prisoner's Dilemma Game iteratively.

- Each agent is represented by two features $(\mu, \rho) \in [0, 1]^2$
  - Memory ratio $\mu = \frac{M}{N}$.
  - Defection rate $\rho \in [0, 1]$.

Assumption

To keep track of all game partners is not always possible.

- Memory size = Number of opponents one can keep track of.

Memory and Interaction Structure

The only way to cooperation is the isolation of defectors.

- Physcial barriers within a spatial structure.

We use memory to tailor interaction structure.

- Memory as a conceptual barrier!

Interaction Rule

Agents are reciprocal and refuse to play with defectors.

Selective Attention

Limited memory size

- Whom to forget and whom to keep in memory?

Selective attention

- Agents are "hard-wired" to pay attention to defectors.
- Forget preferentially cooperators.

Memory and Perception

For only a limited number of its opponents, an agent keeps following information in its memory

- the number of defection received from the opponent
- the total number of plays with it.

Their ratio gives the *perceived defection rate* of the opponent.

Perception

- If opponent's perceived defection rate is ≥ 0.5, opponent is perceived as a defector.

Possible Misperceptions

Misperceptions due to the exaggerated faith in small numbers.

- A cooperator, with low defection rate, can defect more than cooperate within a small number of interactions.

Simplified Example

A "Mostly" cooperator with $\rho = 0.\overline{3}$,

- CCD $\ldots \rightarrow$ perceived as cooperator.
- CD~~C ...~~ $\rightarrow$ perceived as defector!
- D~~CC ...~~ $\rightarrow$ perceived as defector!

Rounds

In each round, a pair of agents is selected to play PD game.

- if neither of the two refuses to play, game takes place.
  - Each receive payoffs according to their joint actions.

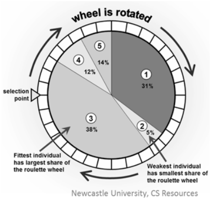
Number of rounds $= \tau\binom{N}{2}$

- Accumulated payoffs are called as *scores*.

Evolutionary Dynamics

Probability of reproduction

$$\text{fitness}_i = \frac{\text{score}_i - \text{score}_{min}}{\sum_j (\text{score}_j - \text{score}_{min})} \in [0, 1]$$



Roulette wheel selection

At the end of one generation

Repeat N times

- Select an agent for 'asexual" reproduction
- Mutate one gene of the offspring genotype with probability r

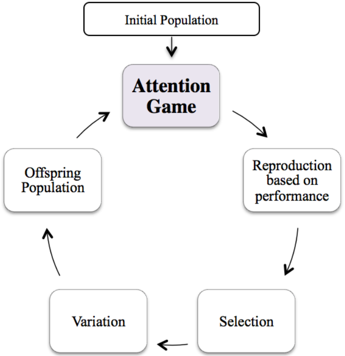
Cut out parents to keep population size as N

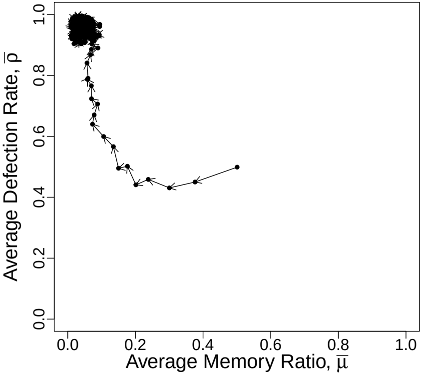
Evolutionary Dynamics

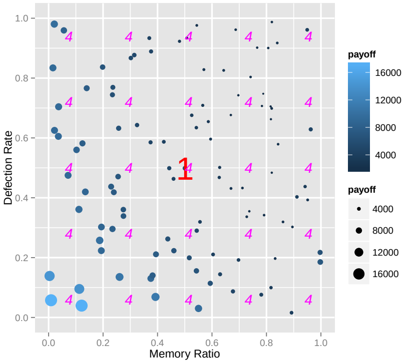
The average genotype of the current population is given by

- $\overline{\rho} = \frac{1}{N} \sum_{i=1}^{N} \rho_i$ and
- $\overline{\mu} = \frac{1}{N} \sum_{i=1}^{N} \mu_i$, respectively.

Analysing the values of $(\overline{\mu},\overline{\rho})$ pairs from generation to generation, will make us to see the co-evolution of cooperation and memory.







Play Pause

Figure: Single realisation for $(S, P, R, T) = (0, 1, 3, 5)$.

Memory Barrier to Interactions.

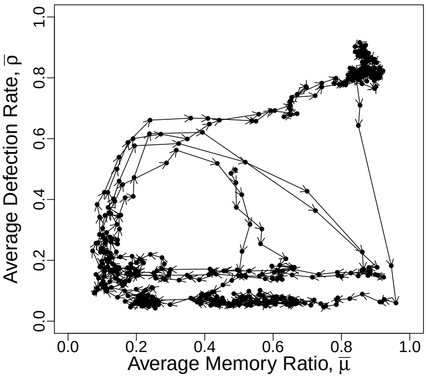
Memory

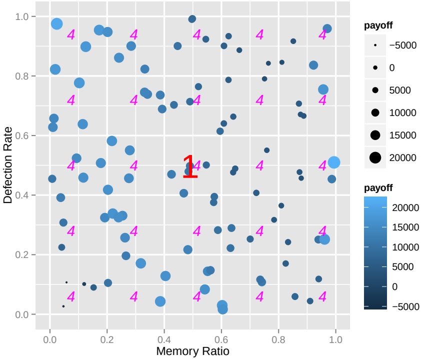
- The surprising downside of having a greater memory size is isolation. Memory blocks interactions that would bring positive payoffs.

Result

Greater memory is unfavourable to evolutionary success when there is no threat.

What if "*receiving a defection*" brings negative payoffs, $S < P < 0 < R < T$?





Play Pause

Figure: Single realisation for $(S, P, R, T) = (-5, -4, 4, 5)$.

Presence of Threat

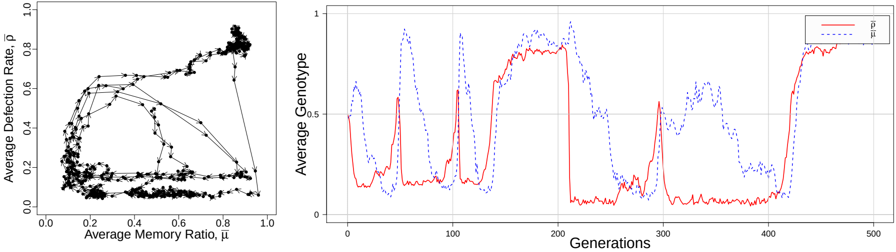


Figure: Co-evolution for $(S, P, R, T) = (-5, -4, 4, 5)$.

Memory Dilemma

In the presence of threat

Two conflicting dynamics compete

- Tendency to increase memory size, in order to maintain self-protection when average defection rate gets higher.
- Tendency to decrease memory size, to avoid self-isolation when average defection rate gets lower.

These two dynamics can give rise to oscillatory behaviors.

The Effect of Payoff Matrix

Which payoff matrix to use?

	C	**D**
C	R	S
D	T	P

Figure: PD Game

	C	**D**
C	$b-c$	$-c$
D	b	0

c

b

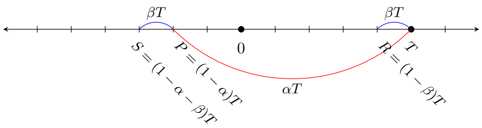
Figure: Donation Game

The Effect of Payoff Matrix

	C	**D**
C	R	S
D	T	P

Greed βT
(benefit for defection)

Threat αT
(cost for receiving a defection)



Each payoff matrix has its own dynamics. To generalise we reformulate IPD payoff matrix with two principal factors:

(i) **Greed factor**: How much it is tempting to defect? (row difference)

(ii) **Threat Factor**: How much it is dangerous to receive a defection? (cloumn difference)

Threat Game

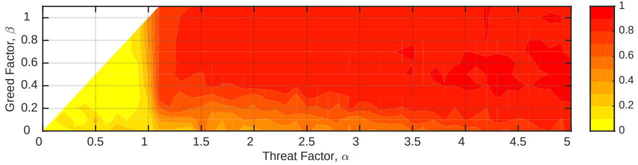
Presence of threat

- For $\alpha > 1$, receiving a defection leads to negative payoffs.

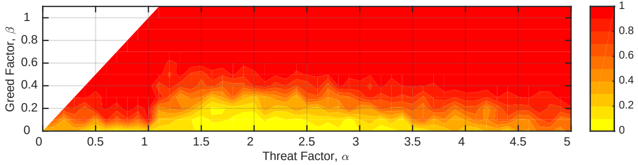
$$
\begin{tikzcd}
 & \mathbf{C} & \mathbf{D} \\
\mathbf{C} & 1-\beta & 1-\alpha-\beta \arrow[d, bend left, "\beta"] \\
\mathbf{D} & 1 & 1-\alpha \arrow[l, bend left, "\alpha"]
\end{tikzcd}
$$

Figure: Receiving a defection brings an extra cost of α (threat factor) and chosing to defect makes an extra benefit of β (greed factor).

Co-evolution of Memory and Cooperation



(a) Average memory ratio $\overline{\mu}$ as a result of threat & greed factors.



(b) Average defection rate $\overline{\rho}$ as a result of threat & greed factors.

Figure: The effect of ecology on the co-evolutionary dynamics.

Results

The dose of the threat makes the resistance for cooperation.

- In the absence of threat ($\alpha \leq 1$),
  - $(\overline{\mu}, \overline{\rho}) \rightarrow (0, 1)$
- In the presence of an appropriate level of threat ($1 < \alpha < \alpha_2$) and under low greed factor ($\beta < 0.5$),
  - Emergent oscillatory dynamics.
  - The subsequent generations evolved to develop some kind of protection against defection.
- Under extreme threat ($\alpha > \alpha_2$) and high greed ($\beta > 0.5$),
  - $(\overline{\mu}, \overline{\rho}) \rightarrow (1, 1)$

Contributions of this Work

- Reformulation of IPD game with threat and greed factors.
  - Drawing boundaries of cooperation
- Co-evolution of memory and cooperation
  - Emergence of an immune response
- The use of memory to tailor the interaction structure
  - Using conceptual structure instead of physical structure.

List of Publications

Threat Game

(1) Uzay Cetin and Haluk O. Bingol, The Dose of the Threat Makes the Resistance for Cooperation, accepted for publication in *Advances in Complex Systems*, 2017, SCI-E.

Attention Game

(2) Uzay Cetin and Haluk O. Bingol, Iterated Prisoners Dilemma with limited attention, Condensed Matter Physics, vol. 17, No. 3, 33001:1-8, DOI:10.5488/CMP.17.33001, 2014, SCI-E.

Fame Game

(3) Uzay Cetin and Haluk O. Bingol, Attention competition with advertisement, Phys. Rev. E, DOI: 10.1103/PhysRevE.90.032801, 2014, SCI.