COMMUNICATION AND COOPERATION

By

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Presented by Diego Soares Cardoso
Motivation

• Communication plays a central role in organization and operation of systems

• Agents base their behavior on signals received and sent
  - Mating
  - Coordinated hunting
  - Computer network protocols
  - Used cars negotiation
  - Price collusion
INTRODUCTION

Assumptions and conditions

• All agents have access to a standard set of identifiable symbols

• Meaning of symbols is induced

• No centralized enforcement mechanisms

• Communication is the only source of information about partners
  - Can only identify a specific agent through potentially mimicked signal sequence

• Agents use finite automata to process, send and react to communication
Expectations

• Defect is a dominant strategy

• “Cheap talk”: no enforceable commitments

• A priori, communication should not alter prediction of mutual defection

• Stark test for the impact of communication
• Mostly related to biological issues

• “Tagging” in iterated Prisoner’s Dilemma
  - Agents “recognize” each other via observable markers

• Refusal to play by past experience

• Agents are more likely to interact with look-alikes
INTRODUCTION

Innovations of this model

• Identification goes beyond passive observation

• Communication schemes are endogenously derived

• Agents can place new meanings on existing signals and invent new patterns

• Agents can formulate strategies about which signals to send in response
INTRODUCTION

Objective

• To gain insight into development and impact of endogenous communication

• Focus on cooperation in a single-shot Prisoner’s Dilemma
INTRODUCTION

Agenda

1. Model
   - Game structure
   - Agent structure
   - Evolving automata

2. Results
   - Patterns of cooperation
   - Patterns of communication
   - How does cooperation emerge?

3. Conclusions
MODEL

Game structure

• 2 agents are paired and play a single-shot Prisoner’s Dilemma

• Pre-play communication is allowed

• Agents simultaneously exchange tokens from a set \{0,1,...,T\}

• Token 0 means player has decided on a final move
  - But doesn’t say which

• Communication continues until:
  - both players issue token 0
  - or number of iterations reaches preset limit
Prisoner’s Dilemma payoffs

<table>
<thead>
<tr>
<th></th>
<th>Cooperate</th>
<th>Defect</th>
</tr>
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<tbody>
<tr>
<td>Cooperate</td>
<td>3,3</td>
<td>0,5</td>
</tr>
<tr>
<td>Defect</td>
<td>5,0</td>
<td>1,1</td>
</tr>
</tbody>
</table>

• No act payoff: -5
  - If player fails to send token 0 during chat limit

• No deal payoff: 2
  - If player issues token 0 but opponent fails to do the same
MODEL

Game structure

• Generation of P agents

• Agent plays the game against every other agent

• Accumulates payoffs for each game

• At the end of generation, strategies undergo selection and modification
**Game structure**

**Example**

- Sends $1_A$
- Receives $2_B$ and decides to cooperate.
- Sends 0
- Since has already decided, continues to send 0

- Receives 0 and decides to defect
- Sends 0

Game is played:
- A cooperates, gets 0
- B defects, gets 5

**Communication and Cooperation. Miller et al. (JEBO 2002)**
Agent structure

- Behavior is controlled by a finite automaton

- Finite internal states \{1, ..., S\}
  - 1 is always the initial state

- Each state contains an action
  - Send a token \{1, ..., T\}
  - or decide a move and send token 0

- Each state has a transition table
  - Next state is determined by received token

- Finite automaton represents a strategy
Example

Token set: \{0,1,2\}

Fig. 1. Automata structure and play (see text for full details).
• Initially each agent is given a random strategy

• Tournament selection at the end of generation
  - Two agents are randomly chosen with replacement
  - Agent with better average score is placed into new generation

• Favors better performing, but does not guarantee the best strategy will survive

• Once selected, strategy suffers mutation with a probability 0.5
  • If so, one state is randomly selected and either
    - the action is altered with prob. 0.5
    - a transition is altered with prob 0.5
MODEL

Evolving automata

• Procedure is repeated $P$ times

• New generation is formed

• Payoffs are reset

• New generation starts: agents play against each other and so on...
Hypothesis
• No systematic tendency toward cooperation should be observed in the system

Observation
• Repeated outbreaks of mutually cooperative behavior occur in the system
Fig. 2. Proportion of mutually cooperative plays by generation for a system composed of 50 agents ($P = 50$), four-state automata ($S = 4$), and two communication tokens ($T = 2$) (bottom ticks represent start of cooperative outbreaks).
RESULTS

Patterns of cooperation

- Cooperation is above threshold 1.6% of the time
- 3.5 epochs of cooperation per 1000 generations
- Average length of 4.5 generations
- Cooperative epochs are **systematic but not periodic**
RESULTS
Patterns of cooperation

Median inter-epoch length
- 155 generations
- Min: 2
- Max: 1537

Fig. 3. Cumulative distribution of generations between cooperative epochs for a system composed of 50 agents ($P = 50$), four-state automata ($S = 4$), and two communication tokens ($T = 2$), across 50,000 generations.
Fig. 4. Average length of communication by generation for the experiment shown in Fig. 2 (bottom ticks represent start of cooperative outbreaks).
Patterns of communication

Fig. 5. Number of unique conversations by generation for the experiment shown in Fig. 2 (bottom ticks represent start of cooperative outbreaks).
RESULTS

Patterns of communication

20 experiments, 5000 generations each
• S = 3, 4, 6, 8, 10, 12 → Processing complexity
• T = 1, 2, 3, 4 → Language complexity

• C = average number of cooperation epochs per 1000 generations
• L = average length per epoch
• P = periods of significant mutual cooperation per 1000 generations

\[ C = -8.22 + 2.45S + 2.30T + 0.23ST - 0.13S^2 - 0.46T^2, \quad R_{\text{adj}}^2 = 0.91, \]
\[ L = 2.48 + 0.54S - 0.20T + 0.02ST - 0.02S^2 - 0.04T^2, \quad R_{\text{adj}}^2 = 0.80, \]
\[ P = -35.64 + 10.17S + 6.10T + 2.15ST - 0.48S^2 - 2.04T^2, \quad R_{\text{adj}}^2 = 0.93. \]

*T and T² not significative
RESULTS

Patterns of communication

Fig. 6. Predicted number of cooperative epochs.
RESULTS
Patterns of communication

• Effect of 1 additional state:
  • C: +1
  • L: +0.3
  • P: +8.4

• Effect of 1 additional token:
  • C: +1.7
  • L: +0.15
  • P: +12

Increased processing and language complexity  More and longer cooperation epochs
RESULTS

How does cooperation emerge?

• Are cooperation epochs generated by pure randomness?

• Simple test: remove selection
  - Only mutation, “random-walk in strategy space”

• Cooperation patterns then disappear

Explanation: adaptive process sequentially creates and destroys key strategy types
RESULTS

How does cooperation emerge?

**Stage 1**: domination by “no communication and defect” (NCD)

![Graph showing proportion of NCD strategies over generations](image)

Fig. 7. Proportion of “no communication and defect” strategies for the experiment shown in Fig. 2 (bottom ticks represent start of cooperative outbreaks).
RESULTS

How does cooperation emerge?

Stage 1: domination by “no communication and defect” (NCD)

- Why strategies don’t try to communicate first and defect?
  - Perpetual communication yields lower payoff
  - Intense communication is more vulnerable to mutations
RESULTS

How does cooperation emerge?

**Stage 2:** emergence of “communicate and reciprocate” (CRC)

- Begin by communicating
  - If opponent communicates back, cooperate
  - Else, defect

- NCD and CRC can coexist

- NCD has little selective pressure

- CRC is improbable
  - Accumulated mutations along the states are maladaptive
RESULTS

How does cooperation emerge?

**Stage 3:** emergence of cooperation

- CRCs are protected from NCDs
- When 2 CRCs meet, they get higher average payoff
- Selection pressure leads to rapid CRC domination
RESULTS

How does cooperation emerge?

**Stage 3: emergence of cooperation**

Fig. 8. Proportion of “communicate and reciprocate communication” strategies for the experiment shown in Fig. 2 (bottom ticks represent start of cooperative outbreaks).
RESULTS

How does cooperation emerge?

**Stage 4:** emergence of mimics who “communicate and defect” (CD)

- CRC is vulnerable to mimics
- CD achieves a higher payoff against CRC
- Selective pressure destroys cooperation and leaves a population of defecting mimics
- Emergence of mimics is facilitated by adaptive system
- Elaborate “handshakes” are equally vulnerable
RESULTS
How does cooperation emerge?

Stage 5: “communicate and defect” (CD)

- CD becomes dominant

- Selective pressure to minimize amount of communication
  - But transition to NCD is slower
Robustness

• Extensive robustness testing of model assumptions with different:
  - Selection, crossover and mutation mechanisms
  - Population sizes
  - Payoffs
  - Matching mechanisms
  - Developers (2) and languages (2)

• Results have minor quantitative variations

• Patterns persist
CONCLUSIONS

Bottom line

• Contrary to expectations, communication allows emergence of cooperation in a single-shot Prisoner’s Dilemma

• Processing and language complexity play a role in such behavior
CONCLUSIONS

Personal view

- Transitory, out-of-equilibrium phenomenon
  - Traditional equilibrium analysis would probably have missed it

- Proposed system might be analytically intractable
  - Perhaps approachable by Population Games

- Effect of processing and language complexity is not well explained
Thank you!