

Cognition and Evolution of Collective Action: Intention Recognition

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Introduction - 1

- We want to understand how collective action and cooperation emerge from the interplay between population dynamics and individuals' cognitive abilities, namely an ability to perform Intention Recognition (IR)
- Individuals are nodes of complex adaptive networks which self-organize as a result of the aforementioned individuals' cognition

Introduction - 2

- We shall investigate how an IR ability alters emergent population properties
- We study how players self-organize in populations engaging in games of cooperation
- We shall employ Evolutionary Game Theory (EGT) techniques and consider the repeated Prisoner's Dilemma

Introduction - 3

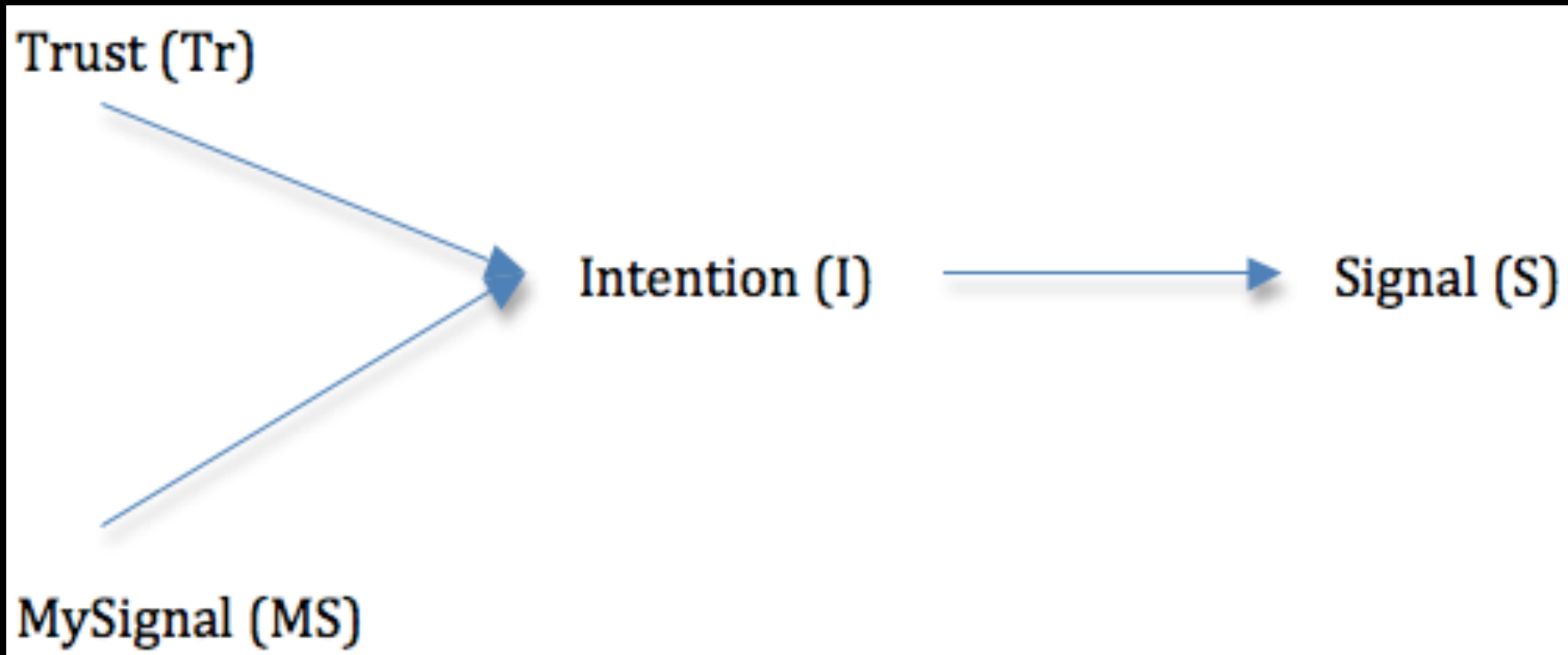
- We study how a player participating in a repeated Prisoner's Dilemma (PD) can benefit from being equipped with an ability to recognize the intention of other player
- Intention recognition is performed using a Bayesian Network (BN) and taking into consideration the present signaling information, and the trust built upon the past game steps

Experimental Setting

- **Prisoner Dilemma.** Two players A and B participate in a repeated (modified) PD game
- **At the beginning of each game step, two players simultaneously signal their choice**
- The payoff matrix is as follows, where $b > 1$:

1	1-b
b	0

Bayesian Network for IR



Trust: How much the other player trusts me

Signal, MySignal: Cooperate (C) or Defect (D)

Intention (hypothesized): C or D

Signal, MySignal: Observed (evidence) nodes

Conditional Probability Tables

- Inference in a BN is based on so-called Conditional Probability Distribution (CPD) tables, providing $P(X | \text{parents}(X))$ for each node X of the BN
- So, for our BN for IR we need to determine:
 - Trust (specifying prior probability of node Trust)
 - CPD table for node Intention, specifying $P(\text{Intention} | \text{Trust}, \text{MySignal})$
 - CPD table for node Signal, specifying $P(\text{Signal} | \text{Intention})$
- Mark that Signal and MySignal are observable (evidence) nodes

Computing Trust

The probability that another player trusts me is defined as how often I kept my promise, i.e. that I acted as I signaled. **It can be given by:**

$$Tr(t) = \frac{1}{2} + \frac{\alpha - 1}{2} \frac{\sum_{i=1}^{M-1} z_i \alpha^{i-1}}{\alpha^M}$$

where

- $\alpha > 1$ is a constant, representing how much the trust in a step is weighted more than its previous one
- M is the number of recent steps being considered, representing the player's memory

- $z_i = \begin{cases} 1 & \text{if I kept promise at step } i \\ -1 & \text{otherwise} \end{cases}$

Probability of a signal given intention

How to update the conditional probability, e.g. of the other player producing signal C given that he intends to C (D)? It is defined as how often he did C (same for D) after having signaled C, in previous steps. It can be given by:

$$p(S = C | I = C) = \frac{1}{2} + \frac{SCT}{2SC}$$

where

- SC is how many times the other player signaled C in recent M steps
- SCT is how many times the other player signaled C and did C in recent M steps

Intention recognizer's strategy:

- At each step, the (frequency) probabilities of the other player having the intention of C or D, given his signal s_1 and my signal s_2 , are computed:

$$p(I=C | S = s_1, MS = s_2) = p(C,s_1,s_2) / p(s_1,s_2)$$

$$p(I=D | S = s_1, MS = s_2) = p(D,s_1,s_2) / p(s_1,s_2)$$

These probabilities are computed based on the CPD

- Then, the player with the intention recognition ability plays C if he recognizes that it is more likely, and D otherwise

Experiments' setting - 1

- We consider a finite population of three equally distributed strategies
 - L_all_D : always signal C and play D
 - T_all_C : always signal C and play C
 - C_IR : always signal C and play IR
- At a step, each individual interacts with all others, and its payoff is collected from all the interactions

Experiments' setting - 2

After REP steps, a synchronous update is performed:

- All pairs A and B of individuals are selected for update, based on their fitness —collected payoff through REP steps
- The strategy of A will replace that of B with a probability given by the Fermi function:

$$p = \frac{1}{1 + \exp(-\beta(f_A - f_B))}$$

Experiments' setting - 3

- Currently, memory size $M = 20$
- We experimented with different values of REP and b
- We envisage that the emergence of cooperation depends on how well the IR performs, which in turn depends on
 - the rate REP/M
 - the difficulty of the PD —defined by the value of b

Preliminary Results

Let NCs, NDs be the numbers of cooperators and defectors in the final population — NCs is total of $T_all_C + C_IR$ and NDs the remaining

Our experiments have shown that:

- NCs is monotonic on REP: the intention recognizers perform better when they have more time to interact and learn
- NCs is monotonic on b: harder PD favors defectors
- For any value of REP tried, for $b = 1.2 \ 1.4 \ 1.6$ the population ends up with all cooperators
- In harder Prisoner's dilemmas, sometimes defectors dominate, and its frequency is decreasingly monotonic on REP

Some details

- The population here has 100 individuals
 - 33 L_all_D 33 T_all_C 34 C_IR
- For each value of b , we ran 100 times the simulation and took the average. Moreover, for

$b = 1.8$:

REP	22	25	30	40	50
NDs	29	18	8	2	0
NCs	71	82	92	98	100

$b = 2.0$:

REP	22	25	30	40	50
NDs	85	65	35	12	3
NCs	15	35	65	88	97

Concluding Remarks

- Adding individuals with an ability to recognize the intention of others based on their past actions enables emergence of cooperation
- The IRs can recognize who are the bad and who are the good, and that enables to defeat the bad

Future Work - 1

- Experiment with populations with different fractions of strategies, in order to see what is the minimal fraction of IRs needed for cooperation to emerge
- Experiment with other (important) parameters, such as β —intensity of selection, etc.
- Mathematical analysis of the models

Future Work - 2

- We will further study how a player participating in a repeated game, or an individual in an evolutionary setting, can benefit from being equipped with an ability to recognize the intention of others
- In the context of evolutionary game theory, we will also study the emergence of cooperative collective intentions from initial intentions in a population

Future Work - 3

- We will employ the models developed in our previous studies to tackle issues like integrating the modeling of trust, reputation, punishment, emotion, etc., in population simulations
- We will attempt to develop a model to analytically study the effects of such aspects to the emergence of cooperation, embedding them into an integrated intention recognition decision making model

Future Work - 4

- In games where an option of (altruistic) punishment is allowed, a BN cause node for representing emotion will be added at the pre-intentional level
- Whether an individual chooses to punish another is enacted, we believe, by his emotion towards the other —something accumulated through past interactions, either direct or indirect

Thank you!

Questions?