Between utilitarian reciprocity and compassionate altruism: an agent-based simulation of the evolution of prosocial behavior

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METHOD
Description of the model

In this section we provide a detailed information of the Agent-Based Model (ABM) presented on this paper, as well as the settings for the simulations. We call the model Evolutionary Prosocial Behavior Algorithm 1.1 (EPBA_1.1).

Entities
Individuals are modelled as agents $i \in \Theta$, where Θ denotes the population or set of agents. Agents can reproduce or die, that is to say, leave or enter the simulation, and their properties evolve over time. For the simulation, the initial size of the population is $N = |\Theta| = 1000$ agents.

Helping other agents
When agent i helps another agent $j \in \Theta$ at the time t_0, she gives a certain amount ξ^{giv} of her resources to j: in the following moment, $\xi_i(t+1) = \xi_i(t) - \xi^{giv}$ and $\xi_j(t+1) = \xi_j(t) + \xi^{giv}$. We denote by the dichotomous variables α and ρ the moments of giving and receiving help, respectively:

$$\alpha_i(t) = \begin{cases} 1 & if\ i\ gives\ help\ in\ t \\ 0 & otherwise \end{cases} \qquad \rho_i(t) = \begin{cases} 1 & if\ i\ receives\ help\ in\ t \\ 0 & otherwise \end{cases}$$

Help can only be given if the endowment is high enough to share the resources. That is to say, agent $i \in \Theta$ will only consider to help at time t if $\xi_i(t) > \xi^{giv}$. Agents can give help to others with a higher endowment.

Properties of the agents
Every agent $i \in \Theta$ has a set of properties that evolve with the simulation.

- Position: agents are located in a two-dimensional plane. In the plane, they can perceive other agents that are inside the Euclidean ball of radius $\delta \geq 0$ centered on the agent. We call this ball the area of influence, and its radius is equal for all agents. For the simulation, the map is based on a square torus plane which measures 5000*5000 points; the agent dimension is equal to 50*50 points. At the start of the experiment the agents are randomly located over space. All agents can move with a constant speed, in units of 20 points.
- Resources: every agent has a certain endowment, an amount $\xi_i \in \mathbb{R}$ of resources. Resources are used to reproduce and to help other agents. At every time t, the endowment of agents increases by a certain percentage $\xi^{\%} \in [0,1]$, so that $\xi_i(t+1) = \xi_i(t) \cdot (1 + \xi^{\%})$.
- Level of altruism: agents have a certain level of altruism, $A_i(t)$, which evolves over time. As proposed by Fetherstonhaugh, et al. [43] the strength of the altruism motive can be computed by an inverse decay and decay function based on the psychophysiological characteristics of human sensitivity over time, with a maximum value $A_i(0)$ that is negatively affected by recent helping actions, and only restored to its original setting after a certain time. Results can be computed by using a time discounted function to detect the

altruism level at each moment, depending on the previous level of altruism and whether the agent has just helped another.

$$A_i(t_1) = \begin{cases} A_i(0) \cdot (1 - e^{(-t_1 + t_0 - \ln \frac{A_i(0)}{A_i(0) - A_i(t_0)})}) & \alpha_i(t_0) = 0 \\ A_i(0) e^{(-t_1 + t_0 - \ln \frac{A_i(0)}{A_i(t_0)})} & \alpha_i(t_0) = 1 \end{cases}$$

- Level of reciprocity: agents have a certain level of reciprocity, $R_i(t)$, which depends on whether they are receiving help from others. Motivation to help for reciprocity over the time follows a decay function as well, related to trust relations experienced and the time passed, based on decay and an inverse decay function from a maximum reciprocity level $R_i(0)$.

$$R_i(t_1) = \begin{cases} R_i(0) e^{(-t_1 + t_0 - ln \frac{R_i(0)}{R_i(t_0)t})} & \rho_i(t_0) = 0 \\ R_i(0) \cdot (1 - e^{(-t_1 + t_0 - ln \frac{R_i(0)}{R_i(0) - R_i(t_0)})}) & \rho_i(t_0) = 1 \end{cases}$$

Reproduction of the agents.

Agents live for $\tau \sim N(\mu, 1)$ periods and, before they die, they can reproduce. In order to do so, they have to achieve a minimum number of interactions φ^{born} and a minimum amount of resources, ξ^{born}. The spawn of an agent $i \in \Theta$ is randomly positioned and has an initial endowment.

Dynamics of the model

All agents $i \in \Theta$ follow the following process simultaneously at every time t.

- Step 1:
  - If $\xi_i \leq \xi^{giv}$, then agent i does not help anyone
  - If $\xi_i > \xi^{giv}$, then agent i can help the agent $j \in \Theta$ inside i's area of influence that minimizes $\frac{d(i,j)}{\xi_j}$:
    - If $A_i(t) > 0$ and $A_i(t) > R_i(t)$, agent i helps agent j for altruism with probability $P = A_i(t)$
    - If $R_i(t) > 0$ and $R_i(t) > A_i(t)$, agent i helps agent j for reciprocity with probability $P = R_i(t)$
    - If $A_i(t) = R_i(t) > 0$, the tie is solved randomly
- Step 2: all endowments, moments of giving and receiving help, and altruism and reciprocity levels are updated. Agents can give help either for reciprocity or for altruism, but they can give and receive help at the same time. If agent i helped agent j, then i moves one unit of distance (20 points) in the direction of j.