

The Evolution of Proximity Based Altruism

András Németh & Károly Takács

Department of Sociology and Social Policy, Corvinus University of Budapest, Fovám tér 8., H-1093 Budapest, Hungary.

The evolution of altruism in humans is still an unresolved puzzle. Helping other individuals is often kinship-based or reciprocal. Several examples show, however, that altruism goes beyond kinship and reciprocity. This refers to situations when people are willing to support others even when this is at a cost and they receive nothing in exchange. Here we examine the evolution of this “pure” altruism with a focus on altruistic teaching. Teaching is modeled as the passing on of knowledge which enhances the survival chances of the recipient, but reduces the reproductive efficiency of the provider. In an agent-based simulation we show that if teaching ability is genetically imprinted and individuals encounter each other on a proximity basis, altruistic teaching will attain evolutionary success in the population. Settlement of the population and accumulation of knowledge are emerging side-products of this evolutionary process.

Humans have a documented tendency to imitate others and to learn from others that is; they are responsive to knowledge provided by non-kin members of the same species¹⁻⁵. Imitation and learning provides clear benefits and does not require the consent of the other individual. On the other hand, teaching, which is also called instruction or social facilitation, requires an active role on the part of the provider that involves costs, and hence it is more difficult to explain how it has been evolved^{3, 6}. A major part of instruction or teaching we observe has previously been claimed as kin-related. The efficient instruction of offspring increases the survival chances of the kin and thus ensures the spread and endurance of genetic material⁷. Kinship based altruistic teaching is viable, as under the right conditions individuals will be more successful in spreading their genes by helping their kin than by acting in their own self-interest⁸⁻⁹. Another major part of teaching is part of an exchange or fueled by expectations and obligations that help will be reciprocated¹⁰⁻¹¹.

There are several studies that highlight examples of “pure” altruism that are beyond kinship-based and reciprocal altruism¹²⁻¹⁴. The evolution of “pure” altruism, and in a specific context, the evolution of teaching behavior that benefits others and not reciprocal, however, is an unresolved puzzle.

In one possible explanation, the teaching of non-kin can be interpreted as an exercise of social influence that prescribes what kind of norms should be internalized and followed in society. There is often a direct incentive behind social influence, for instance, to spread a particular opinion, type of behavior, or value that establishes benefits for the provider.

In another aspect, voluntary teaching can be seen as a contribution to societal welfare or to the provision of public goods. This form of teaching might oblige others to reciprocate indirectly with further contributions. This formalization of teaching links in with research on social dilemmas and the concept of indirect and of generalized reciprocity¹⁵⁻¹⁶. Existing lines of research in this direction suggest that network forms

of generalized reciprocity¹⁵ or local interaction¹⁷⁻¹⁹ might provide a solution for the social dilemma.

In yet another perspective, teaching can be interpreted as the provision of help at a cost and might be contrasted with defective strategies of asking for help²⁰. Simulation results show that providing help could be a successful strategy by preferring old helping partners²⁰⁻²¹. If agents differ with respect to their needs and they are spatially arranged such that they play support games with all their neighbors with a migration option afterwards, solidarity networks will emerge that are characterized by class segregation²²⁻²³. In short, these simulation models can explain how providing support evolves through mechanisms of partner selection. Some other theoretical models build on reputation and image scoring as solutions for similar social dilemmas²⁴⁻²⁷.

We believe that this multidisciplinary variety of research has made significant contributions for understanding altruism, but is inadequate to explain why we encounter “pure” altruistic behavior and support of strangers in human societies that is not reciprocal in any way and is not conditional on previous actions. Teaching or providing help to a stranger is usually not determined by partner selection, but is influenced by a situational context and by the opportunity to interact or simply by proximity²⁸.

The Model

In this study, we outline a simple model that conceptualizes teaching as the passing on of knowledge that involves a cost for the provider. There is no exchange in the dyadic interaction and there is no indirect exchange. Those who already possess the knowledge cannot gain anything more from a partner or from anyone else. They will merely decrease their reproductive chances by spending time disseminating their knowledge. They do not exclusively support their kin or preferred partners, but help

those who are nearby. Such a simple model is lacking in the literature, probably because it has never been thought possible that these assumptions are sufficient to explain the emergence of genetically imprinted altruistic teaching without considering social elements of utility such as fairness or prosocial preferences.

Dyadic interaction The population consists of agents who can be in two states: either having knowledge K or having no knowledge. An agent can attain knowledge from another agent who has K already and who is choosing to bear the costs C of teaching. The costs of teaching appear as opportunity costs that reduce the chance of reproduction. For the sake of simplicity, it is assumed that there is no direct cost in obtaining knowledge and compensation payments are not possible. In our simulation model, knowledge is translated to years added to the baseline life-span. The dyadic interaction between an agent with knowledge K and an agent without knowledge is represented in Figure 1.

Figure 1 somewhere here

As Figure 1 shows, this is an asymmetric interaction in which no exchange or reciprocity is involved. The first agent decides to share knowledge K with the second agent at cost C or not, and if he does, the second agent decides to accept this gift or not. An agent with K cannot get further knowledge or any additional benefits, but cannot lose the knowledge either. The first agent has a dominant strategy not to teach and in this case the second agent does not make any decision. There is no strategic interaction as the choice of the second agent does not have any effect on the payoff of the first agent.

Individual strategies Individual strategies consist of two elements: whether to teach others or not and whether to learn from others or not. Individual inclination for teaching is represented by the T -gene and responsiveness to teaching by the L -gene. Teaching and learning is not dependent on attributes or on previous behavior of the other agent. In this way, four genotypes can be distinguished (TL, T, L, O). At the

population level, types of interactions and average payoffs can similarly be described as in the hawks and doves dilemma²⁹. The proposed proximity based structure of interaction in our model makes analytical calculations extremely difficult and leaves agent-based simulation as a legitimate choice of methodology.

Method In the simulations, the population is scattered in two-dimensional space. In each round (year) an agent with knowledge K searches for an agent without K in his bounded proximity. The likelihood of a match is inversely proportional to the square of distance. If an agent has the teaching gene, this will appear in his phenotype with a certain probability. If this is the case, he will attempt to teach. If the other agent has the L -gene, knowledge K is shared and the expected life-span of the other agent (with the L -gene) is prolonged. Each agent can only be involved in one interaction per year. Knowledge can also be obtained by a small likelihood of innovation.

The likelihood of individual survival is determined stochastically by the life-span parameter. When the population size is fixed, the number of offspring is equal to the number of agents who die in the given year. The cost of teaching appears as an opportunity cost: the chance of reproduction is lower for those who teach in the given year and equal otherwise. Genes are inherited with a certain mutation rate. Offspring are born within the bounded proximity of the breeding agent at a random location.

Results: The Evolution of Altruistic Teaching

Our main hypothesis is that when individuals cannot differentiate between others based on kinship or on previous behavior, altruism in the form of teaching can still attain evolutionary success if individuals interact on a proximity basis. Proximity means that although altruistic teachers are willing to share their knowledge with everyone, they are only able to do so in their milieu. Proximity can also be interpreted in a wider societal context, not just as spatial distance as it is represented in our

model.

The evolutionary success of altruistic teaching is demonstrated by comparing two conditions. In the first condition, matching is random and thus it reflects an unstructured society. In the second condition, interaction only takes place if the actors are within close proximity.

In scarce populations with low mutation rates, we observe the evolution of an overwhelming majority of a single genotype for both conditions. These “regimes” where the entire population has the same genes last long and are separated by short transitions. This kind of dynamics can be explained by modeling population ratios as bounded random walks. In principle, these ratios tend not to change as the births of offspring are proportional to ratios in the old generation. When a genotype is represented by few agents only, however, there is a pressure towards extinction, since the number of offspring in a given year is restricted by population size. Since this applies to all the four ratios, one genotype will attain dominance in small populations.

Transitions do not occur with the same probability between different regimes. Double mutations are unlikely and therefore it is no surprise that transitions between opposite genotypes (TL and 0 ; T and L) occur rarely. Besides, the transition from a TL -regime to a T -regime is much less likely than a transition to an L -regime. Teachers without the ability of learning are unable to benefit from the knowledge of TL -types. If they acquire knowledge by innovation, their breeding chances are decreased by the act of teaching, while they cannot transmit knowledge to their own offspring. This explains why in both conditions of random matching and proximity based interactions, the evolution of regimes of the T -genotype is the least likely. On the other hand, L -types can successfully exploit and invade the TL -population (cf. Figure 2). They benefit from teaching and as they do not teach themselves, they start to breed more efficiently. Some knowledge is preserved only until there are some TL -types around.

Figure 2 somewhere here

At a relatively low mutation rate and in a scarce population, both in the random matching setup and under the condition of proximity based matching, uniform regimes of genotypes alternate each other. With random matching and significant teaching costs, the total length of *TL* regimes is never longer than of other genotypes.¹ The length is measured in terms of effective generations and not in years as living longer is related to having knowledge and this would give a biased indication of the viability of a genotype. Even under the condition of random matching, however, altruists might be the overwhelming majority for a certain time. The explanation lies in the fact that if there is no knowledge, there are no costs of teaching either.

Figure 3 somewhere here

In contrast, altruistic teaching attains an overwhelming success when interactions are based on proximity.² The rule of the *TL*-types occurs more frequently and lasts longer than regimes of other types (cf. Figure 3).³ There are more reasons why proximity helps the evolutionary success of altruistic teaching besides the fact that self-sustaining *TL*-regimes can only be exploited by *L*-types and other regimes are sensitive to mutations in both alleles (*T*, *L*). While one genotype is dominant, other genotypes make several attempts to take over. A concentration of newcomers that is already sufficient for successful invasion is smaller for altruistic teachers than for other types, as they pass on the knowledge to their neighborhood. After they start to propagate, altruists are surrounded mostly by other altruists therefore the benefits of altruistic teaching go mainly to the altruistic teachers themselves. This is a segmentation effect that supports the viability of social traits also in different

¹ For parameter values as in Figure 2, without knowledge at the start and with random matching, the total length of regimes of the *TL*, *L*, and *O* genotypes are approximately the same.

² The analysis has been replicated by omitting variation on the *L*-gene, thus “switching off” genotypes *T* and *O*. Results about the evolution of altruistic teaching in large populations do not differ from the presented results. In small populations, *L*-types are relatively more successful than in the situation without switching off this gene, but their chances to attain dominance lags behind the chances of *TL*-types.

³ For parameter values as in Figure 2, regimes of the *TL*-types last four times longer than regimes of the *L* or *O* genotypes and more than six times longer than *T*-regimes. Results confirm that learning from others (expressed by the *L*-gene) is successful under any circumstances.

contexts^{11,28,30-31}. The success after a smaller concentration also explains why the *TL*-types are the most likely to gain overwhelming success from a randomly mixed initial population (cf. Figure 4).

Figure 4 somewhere here

Settlement Emerges The success of altruistic teaching leads to an emergent phenomenon: to the settlement of agents and to the accumulation of knowledge. This can be explained as follows. Spatial concentration of agents is mainly the result of the rule that offspring are born around the breeding agents. If there is no knowledge in the population, there are no advantageous places for newborns; hence agents are drifting in herds in a random manner. However, if altruistic parents have already acquired knowledge, they live longer and the offspring as well as free riders are taking advantage of settling close to the old generation. The result is a concentrated and settled population. High population density makes it possible to collect knowledge efficiently and maintain a knowledge pool that profits the entire community.

Results: Large populations

If we increase the population size, the model shows non-linear behavior. The success of the *TL*-type becomes more apparent with a small increase in the population size. In a large population, however, the steady states of pure regimes give place to mixed equilibria. The reason is that in a large population, restrictions on reproduction lead to extinction at a much smaller proportion; hence they do not really affect evolutionary dynamics. There is no tendency for an overwhelming rule of one genotype and the evolutionary process resembles an ordinary symmetric random walk. In these neutral circumstances what matters in fact is knowledge.

After acquiring knowledge, *TL*- and *L*-type agents crowd out *T*- and *O*-types, since the latter do not utilize knowledge. In case of random matching, the population is

predominated by L -types. Teachers try to invade from time to time, but they usually die out due to overexploitation, which is the main consequence of random teaching. Unsuccessful invasions provide free riders with knowledge and keep them in majority.

In case of proximity based interaction, the crowding out of O - and T -types is definitely stronger (cf. Figure 5). Altruistic teachers (TL) come to power with a large store of knowledge among them, but free rider learners (L) will continuously exploit them. As L -types procreate more efficiently, their population ratio increases. Once their proportion is relatively high and too few TL -types remain to be exploited, free riders will have higher mortality than teachers, and so their number decreases (cf. Figure 6). These two opposite forces keep proportions of these types within certain bounds and the result is a mixed stochastic equilibrium. Equilibrium proportions, similar to the hawks and doves dilemma, depend on the payoff parameters K and C and on interaction possibilities. Meanwhile in a moderately large population altruistic teachers gain majority, free riders have a higher proportion in case the population is so dense that altruistic teachers cannot escape being exploited (cf. Figure 7).

Figures 5, 6, and 7 somewhere here

The knowledge parameter K , however, has a paradox effect. As knowledge values more in terms of extra life-span, the equilibrium proportion of L -types also increases. This is because with prolonged lifetime fewer TL -types and thus a lower amount of knowledge are sufficient to establish a successful exploitation regime (cf. Figure 8). An increased value of knowledge keeps fewer altruists alive.

Discussion

This paper presented the results of an agent-based simulation to demonstrate how “pure” altruistic teaching that is neither dependent on kinship nor reciprocal could

evolve. Teaching was modeled as a dyadic interaction in which one agent provides knowledge for the other, bears the costs of this action, and receives nothing in exchange. It was not necessary to assume that agents have any kind of cognitive capacity about past interactions nor that they can distinguish between their partners. Results confirmed that altruistic teaching will gain an overwhelming evolutionary success in the population when individuals encounter each other on a proximity basis. Although altruism in this context was specified as the passing on of knowledge to others at a certain cost, the results illustrate how “pure” altruism that is neither kin-related nor reciprocal could evolve in humans. The success of altruism is partly due to local interaction where altruists are likely to meet others with the same genes. The important distinction with kinship based altruism is that in our model, agents do not adjust their behavior towards their kin, nor select their interaction partners based on kinship; they simply help those who are in their proximity. Our result has the implication that besides the evolution of “pure” altruism, much of kinship based altruism that has previously been attributed to “selfish” genes⁷, can also be explained in fact by the principle of proximity based altruism. Results, however, do not imply that proximity based altruism would be in any way more successful than kinship based or reciprocal altruism.

The success of altruistic teaching has led to the emergence of settlement of agents. The population stopped drifting and settled around centers of knowledge. Group formation and settlement was previously linked to economy of scale arguments in hunting and gathering. This paper demonstrated that this phenomenon could also have evolved as a consequence of the spread of altruism.

References

1. Henrich, J. & Gil-White, F. The evolution of prestige: freely conferred status as a mechanism for enhancing the benefits of cultural transmission. *Evol. Hum. Behav.* **22**, 1-32 (2001).
2. Heyes, C. Causes and consequences of imitation. *Trends Cognit. Sci.* **5**, 253-261 (2001).
3. Conte, R. & Paolucci, M. Intelligent social learning. *J. Artificial Societies Soc. Simulation* **4**, <http://www.soc.surrey.ac.uk/JASSS/4/1/3.html> (2001).
4. Conte, R. Agent-based modeling for understanding social intelligence. *Proc. Natl Acad. Sci. USA* **99**, 7189-7190 (2002).
5. Castro, L. & Toro, M. A. The evolution of culture: From primate social learning to human culture. *Proc. Natl Acad. Sci. USA* **101**, 10235-10240 (2004).
6. Tomasello, M., Kruger, A. C., & Ratner, H. H. Cultural learning. *Behav. Brain Sci.* **16**, 495-552 (1993).
7. Dawkins, R. *The Selfish Gene* (Oxford University Press, Oxford, 1976).
8. Hamilton, W. D. The genetical evolution of social behavior: I. and II. *J. Theor. Biol.* **7**, 1-52 (1964).
9. Kaplan, H. & Hill, K. Food sharing among Ache foragers: Tests of explanatory hypotheses. *Curr. Anthropol.* **26**, 223-246 (1985).
10. Trivers, R. L. The evolution of reciprocal altruism. *Q. Rev. Biol.* **46**, 35-57 (1971).
11. Axelrod, R. & Hamilton, W. D. The evolution of cooperation. *Science* **211**, 1390-1396 (1981).

12. Henrich, J. Cultural group selection, coevolutionary processes and large-scale cooperation. *J. Econ. Behav. Organization* **53**, 3-35 (2004).
13. Gintis, H. Strong reciprocity and human sociality. *J. Theor. Biol.* **206**, 169-179 (2000).
14. Bowles, S. & Gintis, H. The origins of human cooperation. In: Hammerstein, P. (ed.): *The Genetic and Cultural Origins of Cooperation* (MIT Press, Cambridge, MA, 2003).
15. Yamagishi, T. & Cook, K. S. Generalized exchange and social dilemmas. *Soc. Psychol. Q.* **56**, 235-248 (1993).
16. Bearman, P. Generalized exchange. *Am. J. Sociol.* **102**, 1383-1415 (1997).
17. Nowak, M. & May, R. Evolutionary games and spatial chaos. *Nature* **359**, 826-829 (1992).
18. Nowak, M. & May, R. The spatial dilemmas of evolution. *Int. J. Bifurcation Chaos Appl. Sci. Engin.* **3**, 35-78 (1993).
19. Macy, M. W. & Skvoretz, J. The evolution of trust and cooperation between strangers: a computational model. *Am. Sociol. Rev.* **63**, 638-660 (1998).
20. de Vos, H. & Zeggelink, E. Reciprocal altruism in human social evolution: The viability of reciprocal altruism with a preference for “old-helping-partners”. *Evol. Hum. Behav.* **18**, 261-278 (1997).
21. de Vos, H., Smaniotto, R. C., & Elsas, D. Reciprocal altruism under conditions of partner selection. *Rationality & Society* **13**, 139-183 (2001).
22. Hegselmann, R. Social dilemmas in Lineland and Flatland. In: Liebrand, W. B. G. & Messick, D. M. (eds.): *Frontiers in Social Dilemma Research* (Springer, Berlin, 1996).

23. Flache, A. & Hegselmann, R. Rationality vs. learning in the evolution of solidarity networks: A theoretical comparison. *Comput. Math. Organization Theory* **5**, 97-127 (1999).
24. Raub, W. & Weesie, J. Reputation and efficiency in social interaction: an example of network effects. *Am. J. Sociol.* **96**, 626-654 (1990).
25. Rapoport, A., Diekmann, A., & Franzen, A. Experiments with social traps IV. Reputation effects in the evolution of cooperation. *Rationality & Society* **7**, 431-441 (1995).
26. Nowak, M. & Sigmund, K. Evolution of indirect reciprocity by image scoring. *Nature* **393**, 573-576 (1998).
27. Wedekind, C. & Milinski, M. Cooperation through image scoring in humans. *Science* **288**, 850-852 (2000).
28. Becker, G. S. Altruism, egoism, and genetic fitness: Economics and sociobiology. *J. Econ. Lit.* **14**, 817-826 (1976).
29. Maynard Smith, J. & Price, G. R. The logic of animal conflict. *Nature* **246**, 15-18 (1973).
30. Flache, A. Stylized solutions for environmental dilemmas in a cellular world. In: Suleiman, R., Budescu, D., Messick, D., & Fischer, I. (eds.): *Contemporary Psychological Research on Social Dilemmas*. (Cambridge University Press, Cambridge, 2004).
31. Bowles, S. & Gintis, H. The moral economy of communities: Structured populations and the evolution of pro-social norms. *Evol. Hum. Behav.* **19**, 3-25 (1998).

Acknowledgements. The second author acknowledges support of the Netherlands Institute for Advanced Study in the Humanities and Social Sciences (NIAS). We thank R. C. Smaniotto, A. Flache, I. Back, B. Janky, and H. Gintis for comments on a previous version of the paper.

Competing interests statement. The authors declare that they have no competing financial interests.

Correspondence and requests for materials should be addressed to K. Takács (karoly.takacs@uni-corvinus.hu). The simulation program was written in Delphi and can be downloaded from <http://www.uni-corvinus.hu/~tkaroly>.

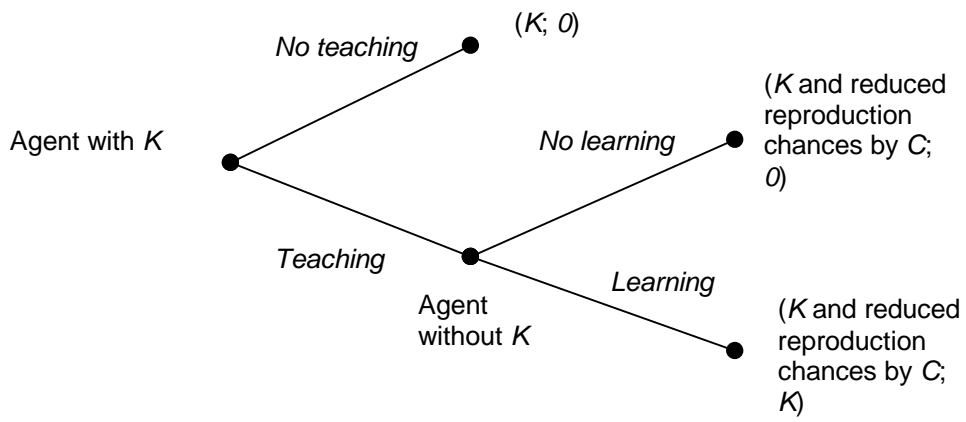


Figure 1: Dyadic Interaction of Teaching

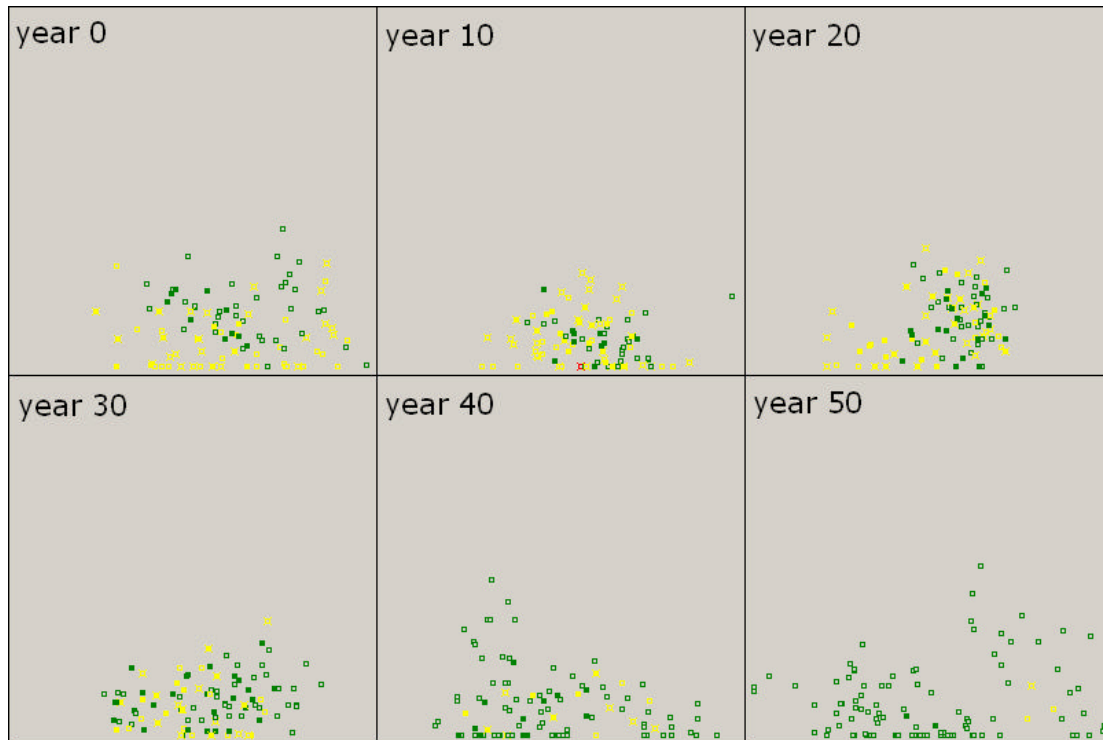


Figure 2: Triumph of Free Riders⁴

Filled squares represent agents with knowledge. Green agents (*L*) exploit yellows (*TL*) gradually (years 0-30). As the yellows weaken, knowledge among greens becomes scarce (year 40). By the end, greens attain an overwhelming success, but have no knowledge (year 50).

⁴ In this example: proximity based interaction, fixed number of agents (100), start from a population of approximately the same number of *TL*-types and *L*-types, mutation rate: 0.1%, innovation rate: 0.1%, breeding range: 20 pixel, teaching range: 32 pixel, baseline life-span: 2 years, *K* adds 2 years, a *T*-gene calls for a teaching phenotype in 50% of the cases and teaching decreases breeding chances by 10% (*C*).

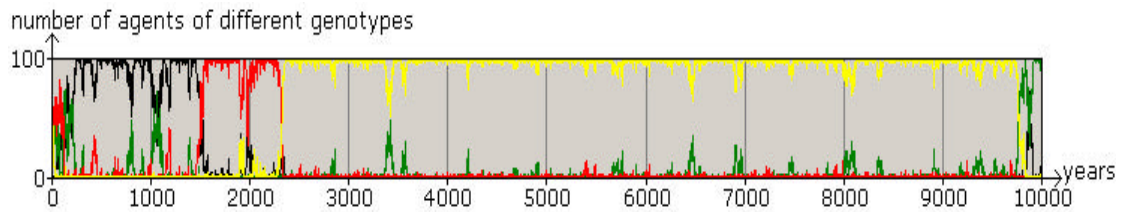


Figure 3: 10000 years of Business as Usual: Domination of Altruistic Teachers⁵

Blacks (O) are invaded by reds (T) in times without knowledge. This is followed by an invasion of yellows (TL) and accumulation of knowledge, with the invasion of greens (L) at the end. Meanwhile there are a lot of unsuccessful bids for power. Altruistic teachers stay dominant significantly longer than others.

⁵ Parameter values are the same as in Figure 2. The domination of yellows (TL) is robust for changes in the auxiliary parameter values.

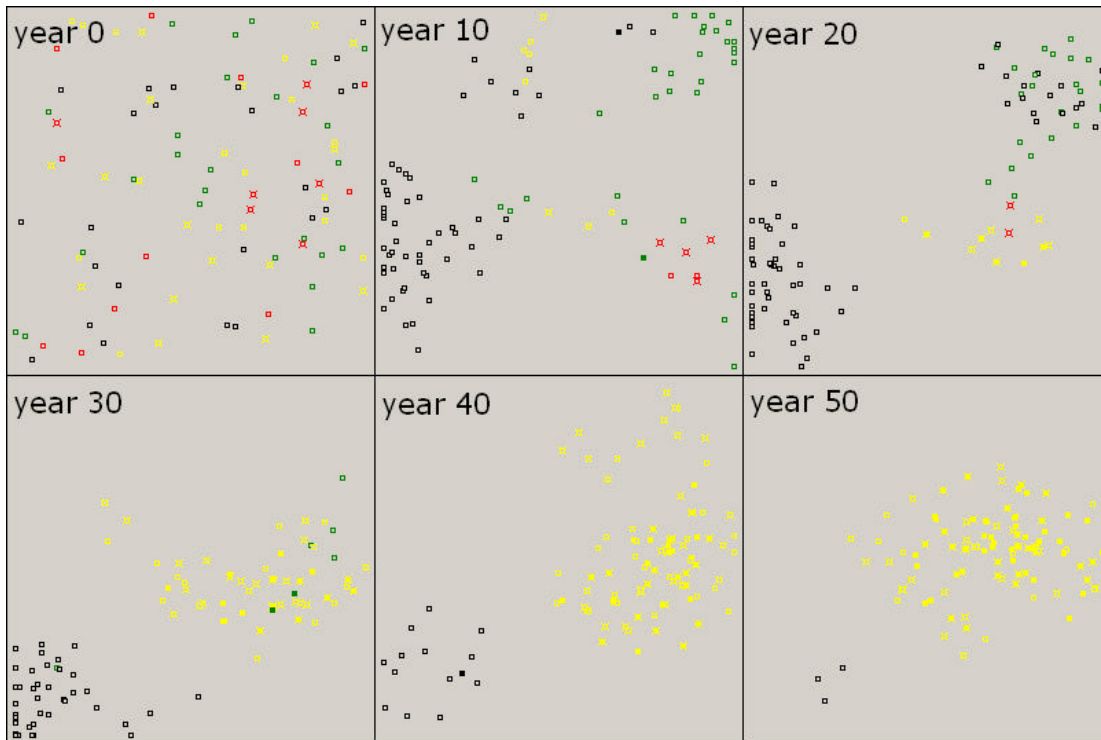


Figure 4: Knowledge is Power⁶

Starting from a random mix of agents (year 0), genotypes become segregated, since new agents are born close to their parents (year 10). Knowledge appears among yellows (*TL*) due to innovation and teaching, while greens (*L*) are mixed with blacks (*O*) (year 20). Although some greens acquire knowledge in year 30, they die out (year 40) and yellows prevail (year 50).

⁶ Parameter values are the same as in Figure 2.

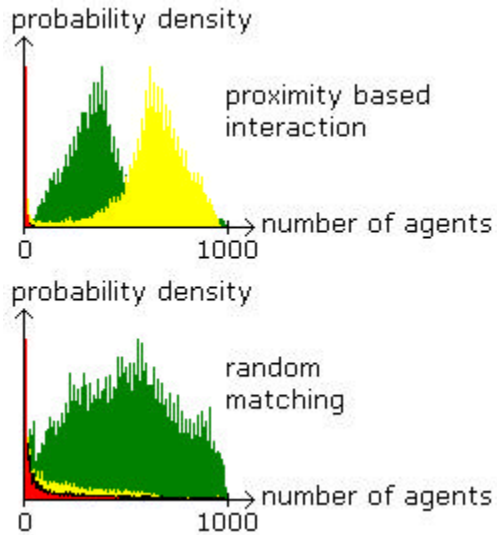


Figure 5: Mixed Equilibrium in a Large Population⁷

Proximity based interaction is a key for success of the *TL*-types (yellow) also in a large population. They have to share the space with *L*-types (green), however, who predominate the population in case of random matching (lower row).

⁷ Parameter values are the same as in Figure 2 except that there are 1000 agents.

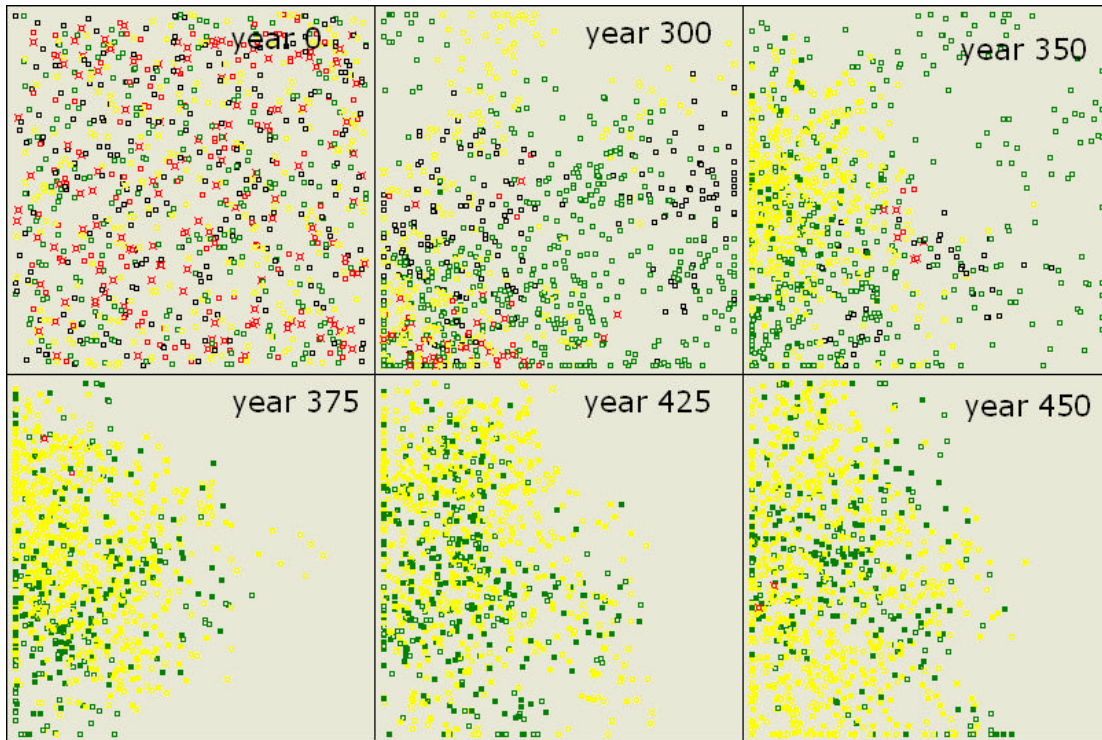


Figure 6: Exploitation and Recovery of Altruistic Teachers⁸

After a random start (year 0) and random processes, yellows (*TL*) attain success and accumulate knowledge (year 350-375). Greens (*L*) are efficient in free riding (year 425), but altruistic teachers recover by establishing centers of knowledge at new locations (year 450).

⁸ Parameter values are the same as in Figure 2 except population size (1000).

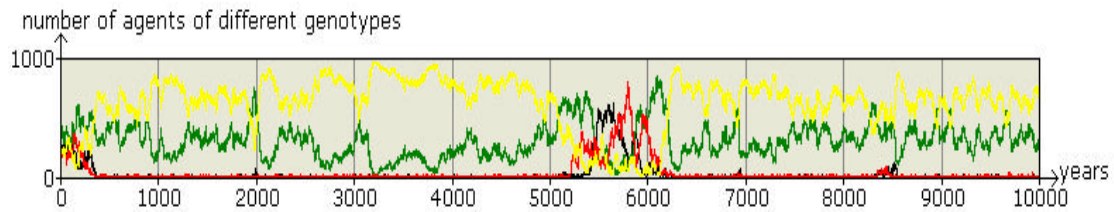


Figure 7: Genotypes Live Side by Side in Large Populations⁹

Increasing population size results in the coexistence of yellows (*TL*) and greens (*L*). Relative proportions fluctuate, as the population goes through the following cycle: greens exploit yellows and increase in number, thus crowding out yellows, which leads to the decrease of knowledge. This in turn weakens greens, which in turn allows yellows to recover at a new location leading again to exploitation by greens.

⁹ This example is for the simulation run represented in Figure 6.

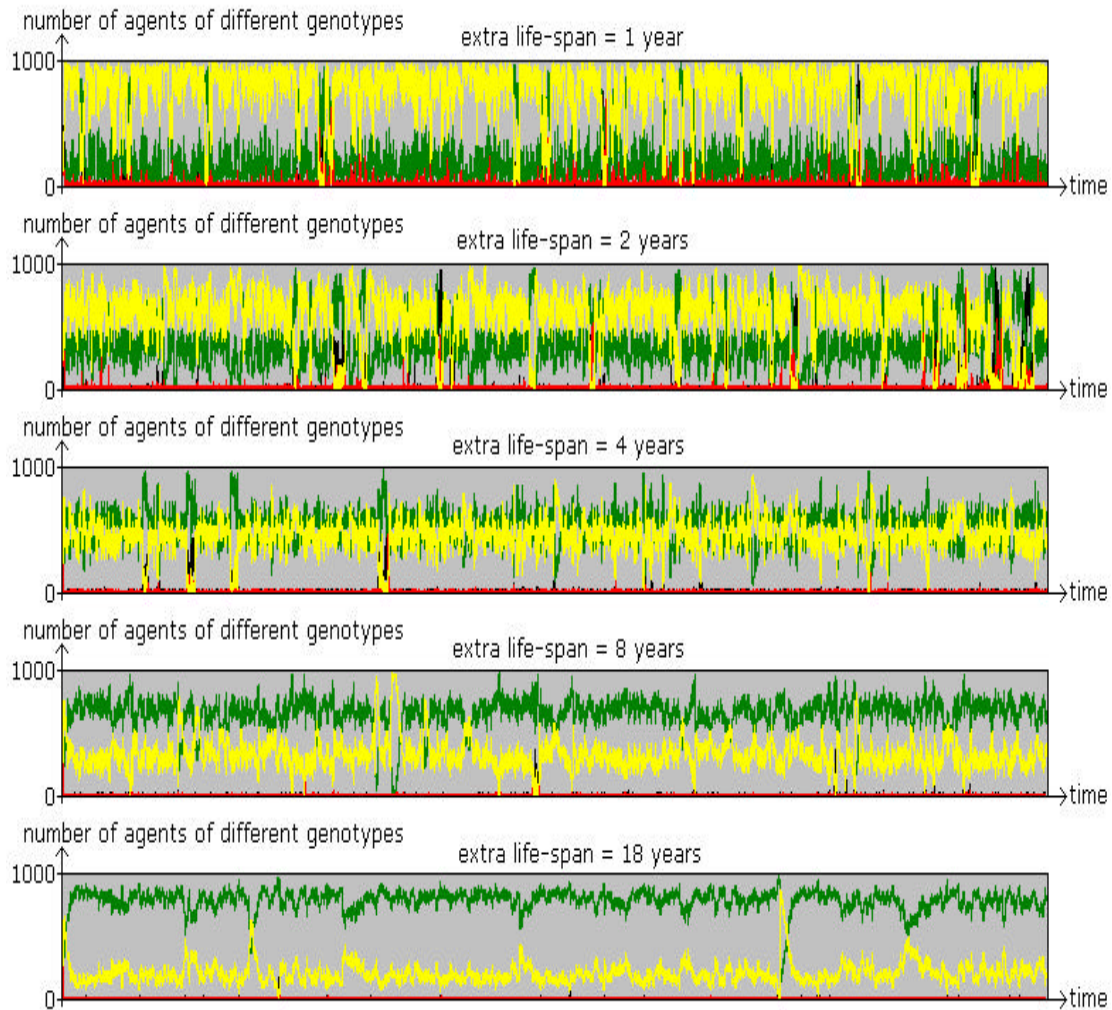


Figure 8: The Paradox of Knowledge¹⁰

By increasing the value of knowledge in terms of extra life-span, the proportion of greens (L) increases in the mixed equilibrium.

¹⁰ Parameter values are the same as in Figure 2 except population size (1000).