The model

The next section describes the model following a compact version of the ODD documentation protocol (Grimm et al. 2010). The computational model is implemented in NetLogo 5.3 (Wilensky 1999).

Overview: purpose

Cooperation Under Resources Pressure (CURP) is an agent-based model designed to explore the evolution of cooperation under different resources scenarios that condition individual needs for survival. The model, inspired by archaeological, anthropological and ethnographic research, is a very stylised abstraction, where the resources pressure is modelled by a stochastic process of acquiring resources (i.e. *prob-resource*) and a parameter of the minimal proportion of the resource unit necessary for survival (i.e. *min-energy*). The model offers different insights about how the resources pressure can change the cooperative behaviour of any group of individuals, although we have a particular interest in the evolution of the sharing practices in hunter-gatherer societies.

Other assumptions incorporated in the model are tested:

- The size of the population.
- The exploration of individuals, modeled by a probability of mutation parameter.
- The size of the tournaments used to model the sharing process and the imitation process.

Overview: entities, state variables and scales

The CURP model is an artificial society of N *people* agents that represent individuals. The number of *people* agents in the model remains constant during simulation. The state variables that characterize each agent are defined in the Table 1. The *people* agent's strategy is defined by the values of *given-energy* and *correlation* variables. *People* agents are not embedded in any spatial structure and can interact with each other with equal probability (well-mixed population assumption).

Table 1: *People* agent's state variables

Parameter name	Brief description
given-energy	The proportion of the resource unit that a *people* agent is willing to share.
correlation	This ranges from -1 to 1, and determines the probability of choosing a donee as follows: for positive values, it represents the probability of selecting the most cooperative donee (with the highest given-energy) between the set of possible donees; for negative values, its modulo represents the probability of selecting the least cooperative donee (with the lowest given-energy) between the set of possible donee; otherwise the donee is chosen randomly.

fitness	The fitness computed as the number of time periods in which the energy obtained by an agent was greater than *min-energy.*

The study parameters of the model (Table 2) are the exogenous variables established by the user that define a simulation scenario, i.e. a computational experiment, and remain constant in each run.

Table 2: Study parameters

Parameter name	Brief description
n-people	Number of *people* agents.
prob-resource	The probability that a *people* agent gets a unit of resource at each time period.
min-energy	The minimal proportion of the resource unit necessary for survival.
sharing-tournament-size	The percentage of *people* agents with no resource at a time period that can be chosen as a donee by a particular donner.
strategy-tournament-size	The percentage of *people* agents of the population that a particular agent considers in the imitation process.
prob-mutation	The probability that a *people* agent decides to follow a new strategy randomly chosen from the strategy space.
rounds-per-generation	*People* agents can change their strategy, i.e. *given-energy* and *correlation*, every *rounds-per-generation* time periods.

To simplify the model, we assume that resources provide a unit of energy to anyone who founds it. A *people* agent who gets resources, gets a unit of energy and shares a proportion of this unit, i.e. *given-energy*, with other unlucky agents. The resources necessary for survival are defined as a proportion of the unit of energy, i.e. *min-energy*. We do not define any temporal scale in the model, time periods do not have meaning, and the analysis is focussed on the asymptotic behaviour of the model.

Overview: process and scheduling

The scheduling is formed by a set of events that take places sequentially in discrete time periods (see Fig. 1). *People* agents perform actions at a random order, avoiding privileging first-acting consequences. The update of the state variables is asynchronous.

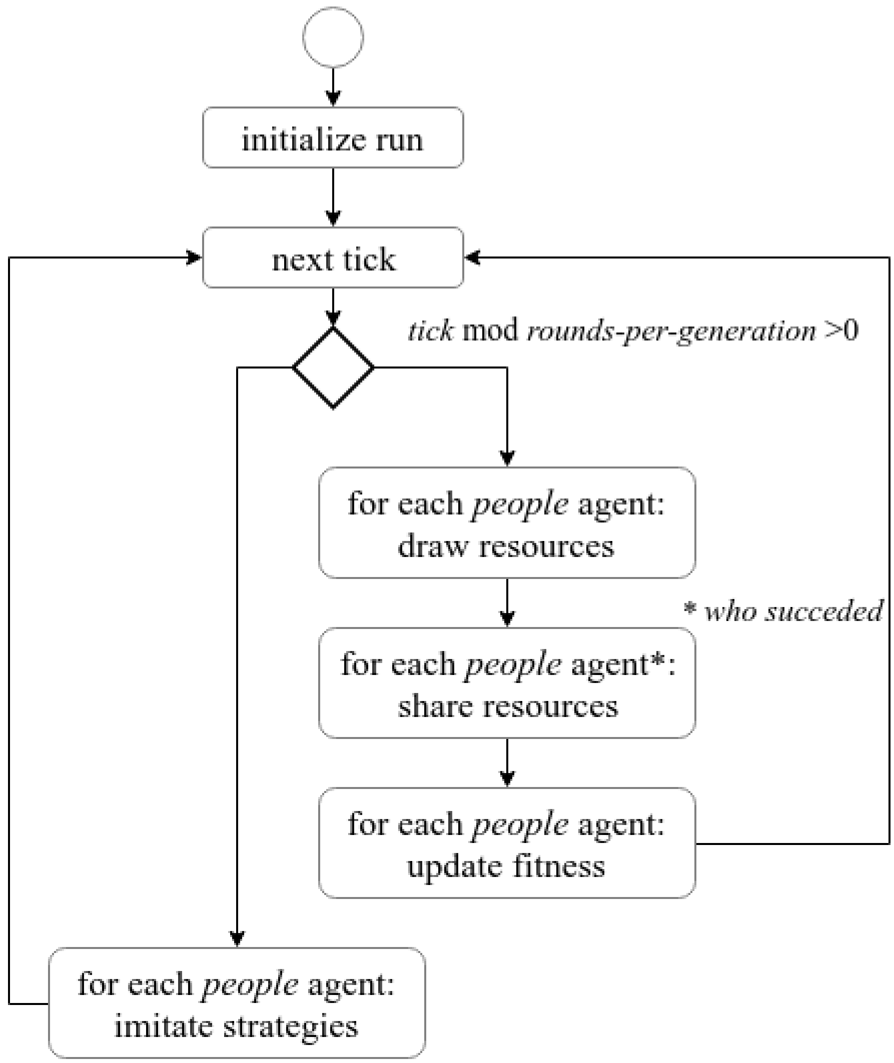

Fig. 1. Flow diagram of the schedule of execution. The order in which *people* agents are chosen in "for each" statements is always random to avoid bias in agent selection.

At each time period each *people* agent draws resources and gets a unit of energy with probability equals to *prob-resource*. Then, each *people* agent who succeeded shares resources following two steps: first she chooses a donee among a set of unlucky *people* agents, and second she gives her a *given-energy* proportion of the unit of energy; any donee will not receive more energy from other donors if she gets more energy than the survival threshold defined by *min-energy*.

For each donor, the set of possible donees is defined as a sampling among all agents who did not get resources (by themselves or from other donors), being the set size limited by *sharing-tournament-size*. The selection of a donee from this set is conditioned by the value of the *people* agent's *correlation*, a variable defined in the interval [-1,1]. When the *correlation* is positive, a *people* agent chooses with probability equals to *correlation* the most cooperative individual in the set (that one with the highest *given-energy* value), otherwise she chooses one individual randomly. In the other case, when the *correlation* is negative, a *people* agent chooses with probability equals to the modulo of *correlation* the least cooperative individual (that one with the lowest *given-energy* value), otherwise she chooses one individual randomly.

Finally, each *people* agent updates her fitness, defined as the number of non-starving time periods, increasing a unit if she has more energy than the survival threshold *min-energy*. The process of drawing and sharing resources, and updating the fitness is repeated *rounds-per-generation* time periods. After this time, each *people* agent updates her strategy,

i.e. the *given-energy* and *correlation* variables, as follows: first she samples *strategy-tournament-size people* agents of the population, and then she imitates the best strategy, i.e. the strategy with the highest *fitness*, if the corresponding *fitness* is greater than hers.

Moreover, each *people* agent always chooses randomly with a probability *prob-mutation* a strategy between the strategy space. This assumption responds to the hypothesis that a *people* agent may prefer to explore new strategies, or there may be some errors in the imitation process.

Initialization

The user initializes a run by selecting the study parameters' values in the interface, corresponding to the scenario to be simulated. The *people* agents are then created according to this parametrization.

Design concepts

The basic principle underlying this model is a problem of cooperation. *People* agents face an unknown distribution of resources. Sometimes they succeed, sometime they do not. Sharing resources can imply a cost in terms of survival, because the proportion of energy shared by a donor is not conditioned by the survival threshold *min-energy*, i.e. a donor always gives a *given-energy* proportion of her current energy although doing that she eventually remains with less energy than the minimum necessary for survival. On the other hand, living in a population where everyone shares can reduce the uncertainty and increase the probability of survival because an individual can get resources by herself or from the generosity of others.

Another interesting question that arises in this problem of cooperation is the decision of who to give resources. You could expect that some reciprocity mechanism emerges in this situations, individuals would prefer to share with others who were generous in the past. Instead of assuming directly reciprocity, the CURP model incorporates a more general rule of selection into the agents strategic behaviour. An individual chooses who to share considering the level of generosity depending on the value of *correlation*; a positive value represents a preference for generous individuals (indirect reciprocity), a negative value represents a preference for selfish individuals, and a zero value represents indifference.

In the CURP model the evolution of the cooperation is the evolution of the level of generosity represented by the *given-energy* variable and the type of reciprocity represented by the *correlation* variable. The evolution of cooperation is not obvious when the probability distribution of resources and the survival threshold change. Individuals in the population will adapt their strategic behaviour in response to the resource stochasticity and survival pressure in a way that is not easily predictable.