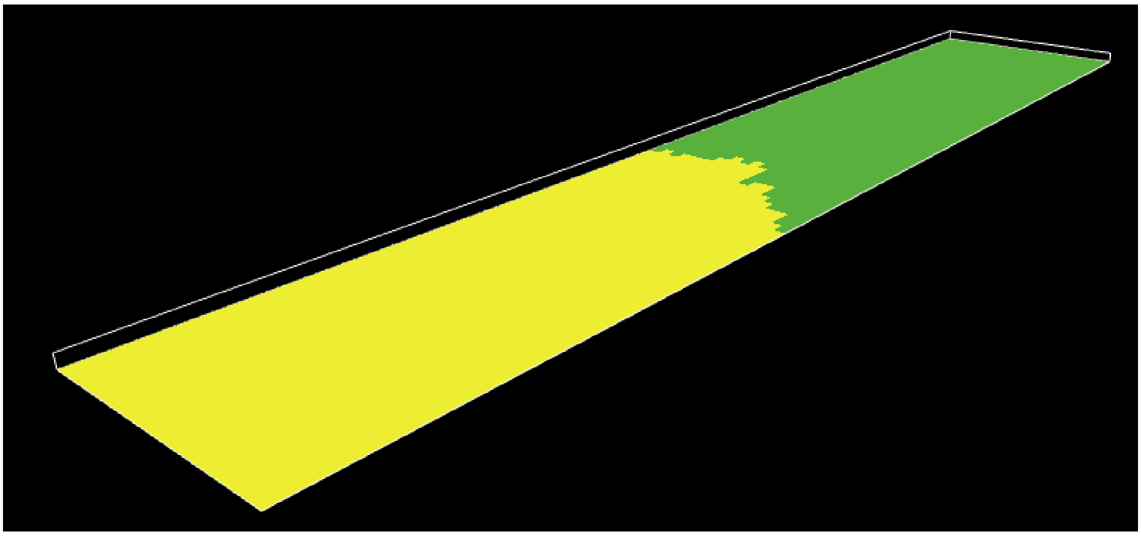
SimulPast Project - Case Study 5

Oasis construction in Central Asia: *The interaction of herding and farming land uses in oases* of Central Asia. Step 1: Competition for land use

The Musical Chairs Model (ODD Protocol)



Andreas Angourakis (a), Bernardo Rondelli (b), Sebastian Stride (a), Xavier Rubio (c), Andrea L. Balbo (b), Verònica Martinez (a), Marco Madella (b, d) and Josep M. Gurt (a)

(a) ERAAUB, Department of Prehistory, Ancient History and Archaeology, University of Barcelona, C/Montalegre, 6, 08001 Barcelona, Spain.

(b) Complexity and Socio-Ecological dynamics (CaSEs), Istitució Milà i Fontanals, Spanish National Research Council (IMF-CSIC), C/Egipciaques 15, 08001 Barcelona, Spain.

(c) Barcelona Supercomputing Center (BSC), Nexus II Building, C/ Jordi Girona, 29, 08034 Barcelona, Spain.

(d) Catalan Institute of Research and Advanced Studies (ICREA).

Overview, **D**esign concepts and **D**etails protocol

Overview

Purpose

This Agent-Based model intends to explore the conditions for the emergence and change of land use patterns in Central Asian oases and similar contexts. Land use pattern is conceptualized as the proportion between the area used for mobile livestock breeding (herding) and sedentary agriculture (farming), the main forms of livelihood from the Neolithic to the Industrial Revolution. We assume that these different forms of land use interact in recurrent competitive situations, given that the land useful for both activities at the same time is limited and there is a pressure to increase both land uses, due to demographic and/or economic growth. As our intention is to create a start point for developing new theories on oases construction in Central Asia, the Musical Chairs model do not represent explicitly the processes underlying land use change, but keep them in a "black box" to be further investigated with more complex models. Furthermore, we have also kept its variables relatively simple, so they hardly can be validated by real data at this stage (e.g. it does not generates spatial patterns).

Entities, state variables and scales

The world of the model is a set of scale-free land units (i.e. patches of land with arbitrary size). It represents an area next to a river, covering both the river banks and the surrounding terrain (i.e. alluvial plain or cone), which are assumed to be able to accommodate either farmlands or pastures.

Agents are the land use variants that can be assigned to land use units. They are differentiated by main land use (`farming`, `herding`), `intensity` and `independence`. Their main (i.e. most extended) land use is represented as the agents' class, while `intensity` and `independence` are agent-level variables (i.e. traits), fixed during the lifetime of the agent. `Intensity` stands for the relative amount of productive factors involved in a land use variant. `Independence` expresses how much a land use variant does not depend on variants with different main land use (e.g. by sharing productive factors). `Independence` is a value between 0 and 1, while `intensity` ranges between 0 and an arbitrary maximum. The maximum for intensity is class-specific and the difference between classes is defined as the parameter `herding_relative_maximum_intensity` (e.g. if its value is 5, then herding is able to achieve five times more intensity than farming). To consider agents to be land use variants instead of people or groups may be a less intuitive and straightforward choice, but allows us to account for all the variety of cases in a rather simpler approach. For instance, competition between land uses could be even a dilemma internal to an individual, with each agent representing a possible individual choice about how to use the land in a specific context.

`Herding` and `farming` land uses are global numerical variables, accounted as land units out of a total given by the size of the world considered in the model. They are calculated at every time step from the population of `farming agents` and they are eventually updated after competition is resolved. Differently to most Agent-Based models, agents are situated randomly in the artificial world, and all processes are independent of those positions. All parameters and variables are displayed in Fig. 1.

Process overview and scheduling

The scheduling of the model consists in a four-step cycle (Fig. 2): the expansion of both land uses (`farming_expansion`, `herding_expansion`), the re-structuring of land use pattern (`update_land_use`) and the checking and resolution of competitive situations between farming and herding, reiterated for each herding agent without access to a land unit (`check_competition`).

First, in the `farming_expansion` and `herding_expansion` procedures, there are four sub-procedures affecting the respective populations of agents:

1. *Intrinsic growth*: the agents are duplicated, depending on a certain probability per time step (`farming_intrinsic_growth_rate`, `herding_intrinsic_growth_rate`);
2. *Extrinsic growth*: agents with random traits are created, up to the number of land units not occupied by the same class, depending on a certain probability per time step (`farming_extrinsic_growth_rate` and `herding_extrinsic_growth_rate`);
3. *Fit-to-maximum exclusion*: both populations are checked to fit within the maximum of the artificial world, while any excess of agents is excluded of the simulation following a random order;
4. *Density-dependent exclusion*: recently created agents of each population are deleted with a probability proportional to the land still available for their type.

Moreover, new farming agents perform yet another procedure, *volition-opportunity exclusion*, in which they test their particular `independence` against the proportion of land currently used by herding (`herding`), as a proxy of the probability of having its extension curbed by their dependency to herding (e.g. if farmers have interest also in the welfare of herds): if the former is lower than the latter, the farming land use variant will be deleted. All excluded agents during these procedures are represented in the output variables `farming_deterrence` and `herding_deterrence` and account for the numerous phenomena that may imply having to discard potential farms or herds due to limiting conditions (e.g. increasing mortality rates, emigrant fluxes moving to any adjacent territory, households changing their livelihood).

The `update land use` procedure assigns the values of the realization of the two land uses, `farming` and `herding`. `Farming` land use is equal to the number of farming agents present in the territory, whilst the amount of land available for herding (i.e. pastures) is given by the difference between the total number of land units and the ones that are used for farming.

The `check_competition` sub-cycle is the reiteration of the resolution of competitive situations between herding and farming (`resolve_competition`), either until all land units required by herding is taken and reconverted into pastures, or the population of herding agents is reduced to the maximum sustained by the current land use pattern. Therefore, its core process (`resolve_competition`) only is activated when there are more herding agents than herding land units (i.e. if there are fewer agents than land units, there is no competitive situation).

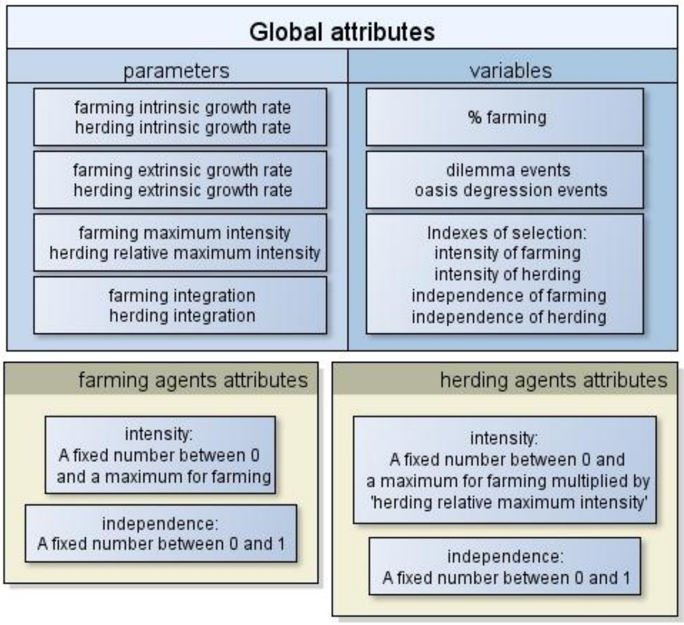


Fig. 1: Global and agent attributes

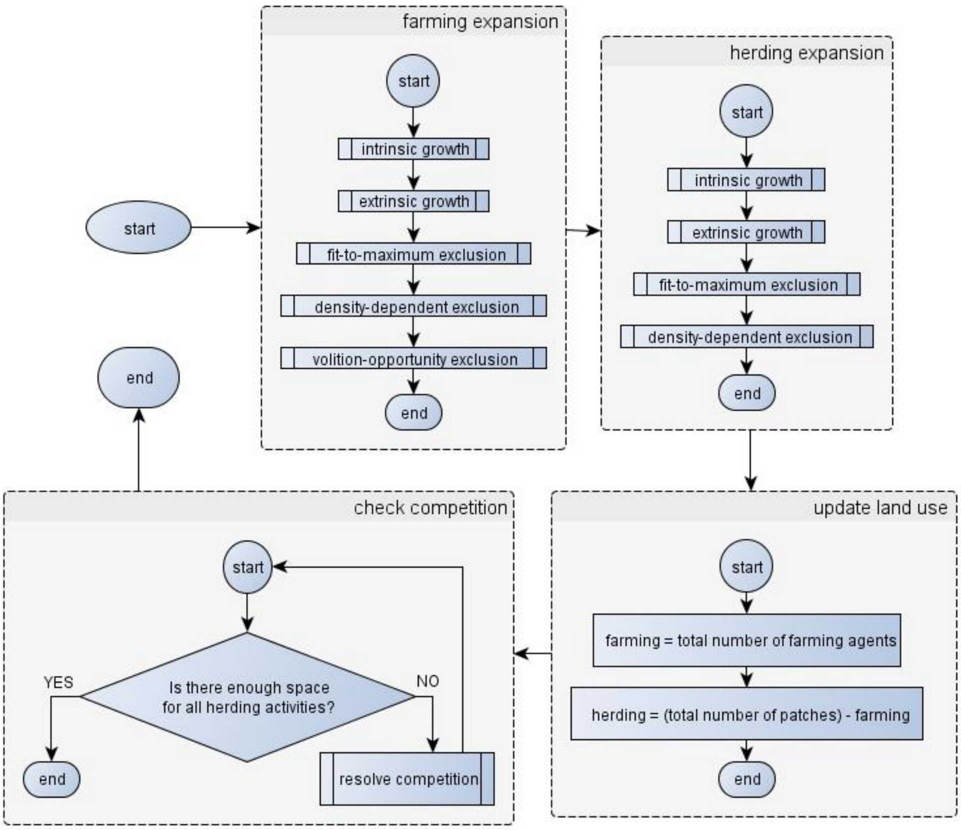


Fig. 2: Flowchart depicting the scheduling and submodels of the Musical Chairs Model

Design concepts

Basic principles

The starting point of the Musical Chairs model is that sedentary agriculture and pastoralism are two livelihoods that entail qualitatively different land uses, and that these land uses are mutually exclusive during a part of the year. Given the assumptions that the demand of land use grows and that the land useful for both activities remains constant, we postulate that there is a recurrent competitive situation between farming and herding. This model presents a solution for such competition, according to which the land use pattern will depend on the intensity, independence and current extension of both classes of land use. Because there are no pay-offs for agents that choose to exit the system (i.e. land use variants that are discarded), the Musical Chairs model cannot be classified as a game (i.e. strategic agents), but simply as a variation-selection process (i.e. rule-based agents). Therefore, its interest relies only in measuring the conditions in which this competition will favour one or another land use.

Emergence

The border between farmlands and pastures is constrained by the possibility of cultivation, imposed in the model by the total number of land units; i.e. farming cannot be extended beyond the world of the model. However, the factual border emerges from the competition between variants of land use characterized by both farming and herding.

Adaptation

In this model agents have a rough capacity for adapting their behaviour by choosing to exit the system or to risk losing their land unit in a dilemma event. However this is actually a selective process from the oasis perspective, since exiting the territory equals discarding a land use variant. True adaptation from the agent perspective will be only possible with the assumption of self-regulating agents (i.e. agents deciding to modify their own characteristics in order to better cope with stress) or considering various interconnected territories simultaneously, instead of assuming regional conditions to always present mid-level opportunity and risk. However, introducing these aspects will not change the results locally, which strictly depend on the external selective factors (i.e. parameters).

Objectives/Fitness

The main goal of all agents is to “survive” as agents, i.e. to acquire and keep the one land unit they need in order to exist as land use variants. In order to reflect the rationale of real decision-making regarding land use, agents’ objectives are summarized as the following rules:

farming

1. Choose the most promising territory, given that the options outside the system are assumed to sum up a mid-level opportunity (i.e. 50% of their land units on average may be freely used for farming);
2. Choose the territory with the least probability of suffering a dilemma event, given that the options outside the system are assumed to sum up a mid-level risk of conflict (i.e. 50% of their land units on average are already used for herding);
3. Once settled in the territory, never consider leaving (i.e. farming investments are not movable).

herding

1. Choose the most promising territory, given that the options outside the system are assumed to sum up a mid-level opportunity (i.e. 50% of their land units on average may be freely used for herding);

2. Choose the territory with the least probability of suffering a dilemma event, given that the options outside the system are assumed to sum up a mid-level risk of generating a dilemma event (i.e. 50% of their land units on average are already used for farming);
3. Once established a territory as a herding route, consider changing it whenever pastures are scarce (i.e. the territory becomes too dominated by either farming or herding)

Agents' fitness is considered through a clear-cut distinction between agents that exists and those that were excluded. Evolution can occur on both populations, through the selection of the traits `intensity` and `independence`. Although the logic of the model previously defines that the values of these traits have a positive relationship with agents' fitness on average, the presence and strength of selection can vary significantly, depending on the conditions given by the parameters.

Learning

There is no learning capacity for agents in the Musical Chairs model. The traits characterizing individual agents, `intensity` and `independence`, are assumed to be not associated with individual learning and intentions. This assumption was made in order to define agents strictly as land use variants, themselves related to an undetermined set of productive factors and decision-makers, and to explore how suboptimal land use variants would survive in different circumstances.

Prediction

As a proxy of prediction, farming agents estimate the risk of participating in a dilemma event (i.e. volition-opportunity exclusion) and herding agents can access the probability of successfully displacing an farming agent (i.e. "1 – `incentive_to_relinquish`") before actually initiating a dilemma event.

Sensing

All agents can sense the quantities of land units both used and potentially usable by their class (i.e. `farming`, `herding`), in order to evaluate the general *opportunity* and *risk* of the territory.

Interaction

Interaction only occurs when a herding agent founds itself without a land unit, and decides to initiate a dilemma event. The interaction arises between this agent and a farming agent (i.e. the two *unlucky* agents) and, if it is the case, their respective supporters. The outcome of this interaction is the deletion of one or another *unlucky* agent, while supporters suffer no consequences.

Stochasticity

Stochasticity is introduced while duplicating agents during the `farming_expansion` and `herding_expansion` processes, while assigning values for `intensity` and `independence` to all agents introduced at initialization and during simulation (i.e. extrinsic growth), while choosing agents for deletion due to the overgrowth of land use demand (i.e. fit-to-maximum and density-dependent exclusions), while choosing agents for engaging in competition and finally while testing the `ratio_of_intensities` as a probability of success of herding during dilemma events.

Collectives

In the Musical Chairs model, the only collectives that affect the outcome are the rather diffuse entities implied in the parameters `farming_integration` and `herding_integration`. These, however, do not behave as agents own their own, but as superposed clusters of the support network existing between agents of the same kind. Therefore, their action will depend directly on the ones taken by the "unlucky" agents summoning them.

Observation

Results of the Musical Chairs can be analysed through four sets of variables, included in Table 2:

1. The proportions of the territory that are involved in each land use, found in `farming`, `herding` or both. If the system is saturated with agents, a straight-forward way to assess land use pattern is a percentage. A more intuitive visualization of this proportion, using green (`farming`) and yellow (`herding`) patches, is available at the model´s interface (Fig. 3, upper-right corner).
2. The variables counting the number of agents that come "in" or "out" the territory during a time step (`farming_growth`, `farming_deterrence`, `herding_growth`, `herding_deterrence`) indicate if a state of the system is receiving or expelling agents of a given class. The difference between growth and deterrence (`farming_balance`, `herding_balance`) point to the existence of equilibrium and its stability.
3. The variables measuring the occurrence of dilemma and oasis degression events, are indicative of the level of potential and actual land use change in the territory during a particular time step.
4. The variables that infer the existence and strength of selection of agents' traits (`mean_fint`, `mean_find`, `mean_hint`, `mean_hind`), by calculating the mean between four groups, weighted by the subpopulation they represent (e.g. if all herding agents have an intensity superior to 75% of the maximum value, then `mean_hint` will be between 3 and 4).

NetLogo's interface offers a graphical visualization of these variables (FIG 3).

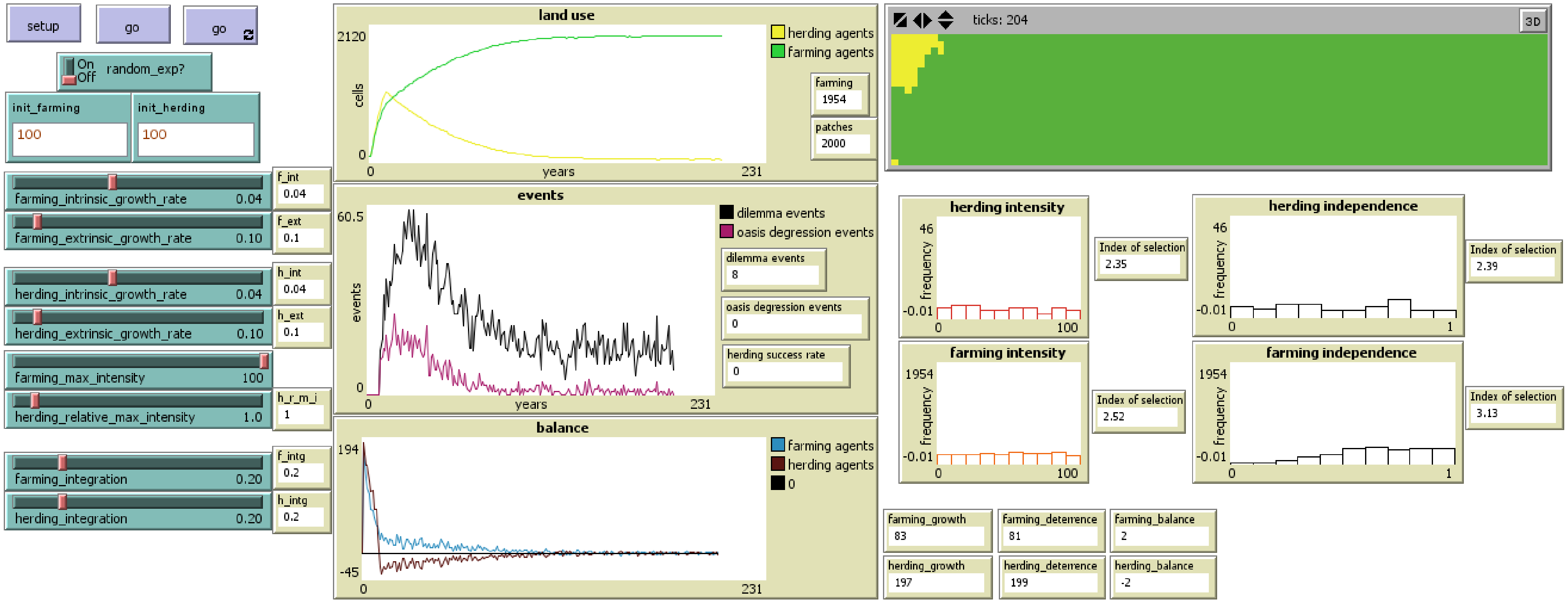


FIG. 3: Snapshot depicting the model´s interface in *NetLogo*

Details

Initialization

In order to be simulated, the model is initialized as follows. First, the world size is defined using as parameter the maximum values for two spatial dimensions (max-pxcor, max-pycor). Then, both populations of agents are generated according to the quantities specified by init_farming and init_herding. Farming agents will be randomly-assigned a value of intensity ranging from 0 to max_farming_intensity, and herding agents will have an also randomly-assigned intensity, but ranging from 0 to the product of max_farming_intensity and herding_relative_max_intensity. However, if the simulation is a randomized experiment, initial populations will be randomly-chosen integers between 0 and the respective values of init_farming and init_herding, and the value of herding_relative_max_intensity will be replaced by a random rational number between herding_relative_max_intensity and its reciprocal (i.e. herding_relative_max_intensity^{-1}), following a skewed distribution with mean 1. Finally, each agent is randomly-assigned a particular value for the variable independence, varying between 0 and 1. All random numbers are chosen from a uniform probability distribution, unless it is stated otherwise.

Input

The model does not use input data to represent time-varying processes.

Submodels

All submodels of the Musical Chairs model represent different processes through which agents are either generated or sorted out of the system. They are here presented following their order in the model's schedule.

Intrinsic growth

The *intrinsic growth* submodel includes the assumption that (1) the demand of land use grows in absence of (exogenous) limiting factors, and (2) it does this following a constant rate. Moreover, (3) growth rates associated with farming and herding land uses were assumed to be equal and (4) fixed at 0.04, a realistic overall value for historical periods preceding the industrial era (note that this value does not represent the actual grow rate, but the maximum grow rate).

This submodel generates pseudo-random numbers between 0 and 1, out of a uniform distribution, for each agent of a population; test it against the fixed rate of growth for the respective population (farming_intrinsic_growth_rate, herding_intrinsic_growth_rate) and duplicates all agents with a number equal or smaller than this rate. This procedure imitates, in an Agent-based fashion, the well-known model of exponential growth.

Extrinsic growth

The basic assumption behind the *extrinsic growth* submodel is that there is a set of agents of a given type willing to immigrate to the model's territory, if the latter presents them an opportunity. These two sets of agents (one for each type) represent indistinctly the potential fluxes of productive factors coming from neighbouring territories not represented in the model. Moreover, the source is assumed to be *unlimited* (i.e. incoming agents could potentially occupy all the territory in a single time-step) and *inexhaustible* (i.e. there will always be potential agents to enter the territory, whatever the volume of past flows).

This submodel first calculates the attractiveness of the territory, in terms of how many land units can further be occupied by a given class of agent: whereas for farming it is equal to `herding`, for herding agents it is the difference between the total of land units and the number of herding agents that were at the territory in the previous time-step. Subsequently, this value is weighted by the externally-given and constant proportion of potential immigrants that will actually enter the territory (`farming_extrinsic_growth_rate`, `herding_extrinsic_growth_rate`) and then rounded. Finally, agents of the respective class are generated up to the resulting integer.

Fit-to-maximum exclusion

This submodel checks that the overall number of agents, including those recently created through intrinsic and extrinsic growth, fits the maximum given by the total amount of land units in the territory. Each new agent will check this condition in a random order and, if not complied, it will be excluded. This mechanism –according to which there cannot be more agents of each class than land units— is a necessary implication of the definition of agents and spatial units in this model: agents are not representation of specific individuals or groups of individuals, but arbitrary units of land use.

Density-dependent exclusion

Similarly to the *Verhulst-Pearl* or *logistic* equation, the density-dependent submodel performs a correction on exponential growth and it penalizes the occupation of peripheral land units. This submodel is based in the assumption that the more extended is a land use is a territory, the lesser the incentives to further extend it.

The density-dependent exclusion sub model is compounded by a single procedure, in which the density of a class of land use (i.e. the number of agents of that class divided by the total amount of land units) is tested against a pseudo-random number between 0 and 1, out of a uniform distribution, for each new agent of that specialization following a random order. Therefore, the density of a population of agents is treated as a proxy of the probability that a specific agent will exit the system.

Volition-opportunity exclusion

This submodel applies only to farming agents, and it describes how the current landscape land use pattern can stimulate or restrain the expansion of farming. It involves two assumptions: (1) that dilemma events are undesirable for decision-makers involved in farming, and (2) that such decision-makers decide to settle new farmlands before the competitive season (i.e. the arrival of herds). The latter imply that the foundation of new farmlands will be done with poor information on if and by which herders a given area will be claimed as pastures. In this sense, the only source of information available is the landscape itself, perceived as the proportion of `herding` land units against the total of land units. On the other hand, this information will be perceived as more or less relevant, depending on how much this farming land use variant depends on herding: if it is completely independent, the decision-makers involved will always press for the expansion of farming and so the new farming agent will always survive this filter. Accordingly to this submodel, each new farming agent will test this perception against its value of independence and, if it is the case that the latter is lower than the former, the agent will exit the system.

Competitive exclusion (resolve_competition)

This submodel accounts for the events occurring during the competitive season, in which herders come to graze their animals inside the same territory where agricultural settlements exist. It presents an answer to the problem of land use competition between these two activities during this season. Two assumptions are needed for this submodel: (1) as it was also the case for the *fit-to-maximum* exclusion, agent's requirements of one land parcel is by definition not flexible, hence not compressible (i.e. the number of agents cannot surpass the number of land units); (2) contrasting with farming agents, herding agents will have access both the extent of farming land use and the conditions of any forthcoming competition (i.e. ratio_of_intensities), because all agents will actually be there to be observed.

This submodel is called recursively, whenever the number of herding agents is greater than the current value of herding land units. Its specific procedures are the following:

1. Two agents of each kind are randomly chosen to be the ones driven into competition (the *unlucky*);
2. Particular helpers are randomly-chosen among the respective populations, according to the predefined ratios of connectivity (farming_integration and herding_integration);
3. The overall intensity of each party is summed up as farming_intensity and herding_intensity;
4. The relative ratio between the intensity of the herder party and that of its opponents (ratio_of_intensities, varying between 0.0 and 1.0) is calculated;

$$ratio\_of\_intesities = \frac{herding\_intensity}{herding\_intensity + farming\_intensity}$$

5. The index of opportunity regarding the amount of land units that could be gained for herding by transforming farmland into pasture (index_of_opportunity, varying between 0.0 and 1.0) is calculated;

$$index\_of\_opportunity = \frac{farming}{"total\ number\ of\ land\ use\ units"}$$

6. The incentive that the unlucky herding agent has for giving up the parcel and exiting the world (incentives_to_relinquish, varying between 0.0 and 1.0) is calculated;

$$incentives\_to\_relinquish = 1 - ratio\_of\_intensities * index\_of\_opportunity$$

7. The value of incentives_to_relinquish is tested against the independence of the unlucky herding agent:
    a. If incentives_to_relinquish is greater than independence, the unlucky herding agent will be excluded from the simulation.
    b. When the opposite is true, the unlucky herding agent will produce a dilemma event by pressing to transform a randomly-chosen farming land unit. Its

realization is given by testing the `ratio_of_intensities` as a probability of herding success (i.e. against a random number between 0 and 1):

i. If `ratio_of_intensities` exceeds this random number, the unlucky herding agent will then acquire the land unit of the unlucky farming agent, excluding this agent from the system and transforming one unit of `farming` into one of `herding`;

ii. If `ratio_of_ intensities` is lower than this random number, the unlucky herding agent is the one to be excluded and the land use pattern remains unchanged.

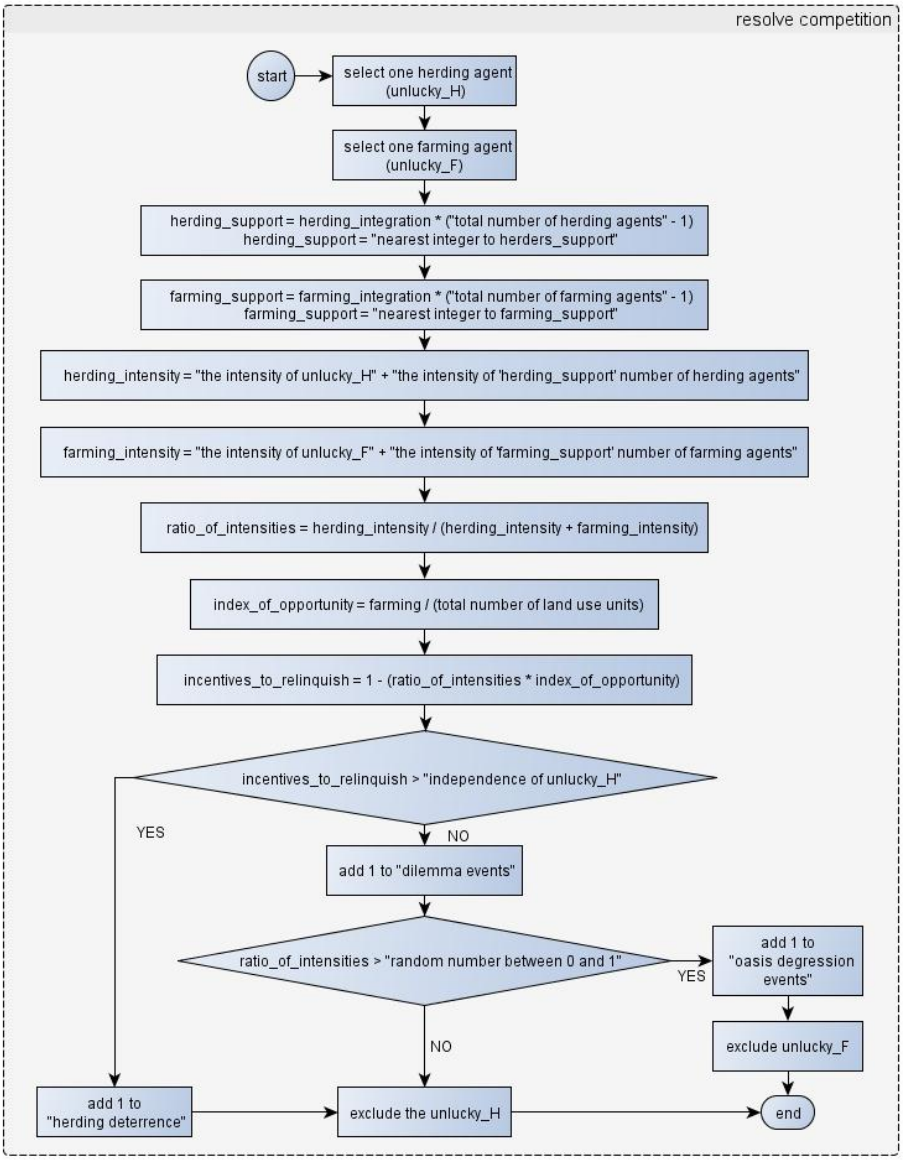


FIG. 4: Flowchart depicting the Competitive exclusion submodel (`resolve_competition`)

Table 1 Parameters	
Name	*Interpretation*
Number of patches	The number of land units available in the territory.
`init_farming`	The initial number of farming land units.
`init_herding`	The initial number of herding land units.
`farming_intrinsic_growth_rate`	The probability that a farming land use variant is duplicated in another land unit during a cycle, given only its own existence.
`herding_intrinsic_growth_rate`	The probability that a herding land use variant duplicated in another land unit during a cycle, given only its own existence.
`farming_extrinsic_growth_rate`	The proportion of farming land use variants out of the total that could be further sustained in the territory, which are pressed by exogenous factors, independently of local variants.
`herding_extrinsic_growth_rate`	The proportion of herding land use variants out of the total that could be further sustained in the territory, which are pressed by exogenous factors, independently of local variants.
`farming_max_intensity`	The maximum intensity that a land use variant can have, if it is characterized by farming.
`herding_relative_max_intensity`	The ratio between the maximum value of intensity that herding land use variants can have and the one reachable by the ones characterized by farming.
`farming_integration`	The proportion of farming land use variants that are connected to a single farming land use variant.
`herding_integration`	The proportion of herding land use variants that are connected to a single herding land use variant.

Table 2

Variables

Name	*Interpretation*
farming	The amount of land units dominated by farming land use.
herding	The amount of land units dominated by herding land use.
dilemma_events	The number of dilemma events per time step.
oasis_degression_events	The number of oasis degression events per time step.
ratio_of_intensities	The ratio between the intensity of the *unlucky* herding land use variant and related variants, and the one of the *unlucky* farming land use variant and related variants.
index_of_opportunity	The ratio between the land units dominated by farming and the total number of land units in the territory; it is a measure of the potential return of turning farmlands into pastures.
incentive_to_relinquish	A ratio-type measure of the incentives to relinquish one herding land use variant, in opposition to the incentives to turn one land unit to herding.
herding_success_ratio	The proportion of dilemma events that became oasis degression events.
independence	The probability that the specific land use variant will be enforced at the expense of one belonging to the alternative class.
intensity	The capacity of a specific land use variant to enforce itself when competing with variants belonging to the alternative class.
farming_growth, herding_growth	The number of new land use variants that can occur (i.e. land use demand) during a time step.
farming_deterrence, herding_deterrence	The number of new land use variants that where discarded (i.e. frustrated land use demand) during a time step.
farming_balance, herding_balance	The difference between growth and deterrence of a land use class. Indicates the net change of a land use.
Indexes of selection of agents' traits (intensity, independence) per agent class (mean_fint, mean_find, mean_hint, mean_hind)	Indexes that identify the existence and strength of the selection on an agents' trait, representing the mean relative frequency of this trait's values separated in four groups, depending on proportions of the maximum value for this trait ([1] 0-25%, [2] 25-50%, [3] 5-75% and [4] 75-100%); if values among agents are randomly distributed (i.e. this trait is not selected), the value of the index will be approximately "2.5".