Ecologia 1.1

Overview, Design concepts, Details

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The Ecologia software is an individual-based model (IBM) for the study of simple ecosystems, designed to be easily adaptable to various theoretical and real-life ecosystems. Implemented in Java, it uses uses discrete time and space modelling in a multi-species setup.

This model description follows the ODD (Overview, Design concepts, Details) protocol (Grimm et al. 2010).

1. Purpose

Ecosystems are complex networks that can be difficult to study *in situ*. Due to an abundance of interacting factors, it is often hard to focus on a single mechanism or process during an investigation. Also, collecting all necessary data in the wild can prove challenging.

Computer simulations can augment traditional ecological research by addressing these problems. First, a simulation can be designed to any level of detail that is desired, thus limiting possible interference from unwanted side effects. This enables one to get a solid grasp of individual effects in a simplified environment before applying that knowledge to more complex real-life scenarios. Secondly, computer models make data-gathering trivial and often greatly reduce experimentation time. Thus they are well suited for experiments that would be too difficult, too costly or too long to perform in real life.

The purpose of Ecologia is to provide a generalized platform for such simplified ecosystem modelling. It is not primarily intended to study any one issue, but designed to be easily extendable to allow many different terrestrial ecosystems to be simulated.

2. Entities, state variables, and scales

Updates. Time in Ecologia is measured in updates, discrete time steps representing one iteration of the simulation.

Tiles. The Ecologia world consists of a tile matrix. Each tile represents one discrete area of ground that may be occupied by at most one animal, or a water tile. Grass grows on tiles, providing food for herbivores. Depending on the local humidity, the grass density on a tile will increase or decrease each turn within a 0-100% range. The grass density also decreases when herbivores feed on a tile. Herbivores can only feed on tiles with a grass density greater than 0%.

Humidity. Each tile has a humidity value, which is a combination of global and local factors. The global humidity can be set to one of the following values: “Saturation” (+2), “Wet” (+1), “Dry” (0), “Drought” (-1) or “Severe drought” (-2). Local humidity can also be affected by the presence of water tiles, which set the humidity of nearby tiles to “Saturation”.

Animals. Animals are the main focus of Ecologia. As of version 1.0, there are two species: herbivores and carnivores. Herbivores feed on the grass that grows on each tile; carnivores hunt and eat herbivores. Both reproduce strictly asexually. Animals have the following state variables:

- *ID number* A unique identifying integer is assigned to every animal.
- *Parent ID* The parent’s ID number.
- *Type* The animal’s species (herbivore or carnivore)
- *Genome* This animal’s genome (see below for details).
- *Age* The animal’s age in updates.
- *Position* The animal’s position in terms of its *x* and *y* coordinates.
- *Energy* The animal’s current energy level. If this reaches 0, the animal dies. Movement and reproduction require energy, feeding restores it.
- *Exhaustion* A numeric factor that limits how many turns in a row an animal can move. Movement increases the exhaustion counter, standing still reduces it again.

Genomes. Each animal has a genome that determines certain core characteristics. At the start of a simulation, a user-defined standard genome is given to all members of a species. At reproduction, the parent genome is passed on to the child, potentially being mutated in the process. A genome consists of the following numeric characteristics:

- *Global mutation rate* This is identical for all species and defines the meta-mutation rate (the mutation rate of the mutation rate).

- *Mutation rate* The percentage mutation rate per “gene” (= genome characteristic).
- *Speed* The number of tiles an animal may move per turn.
- *Stamina* Determines an animal’s capacity to endure exhaustion. When the exhaustion reaches the stamina value, an animal cannot move until it has recovered sufficiently.
- *Sight.* The range of vision of an animal (in number of tiles).
- *Metabolism* Plays a role in how much energy an animal gains from its source of food.
- *Age limit* When an animal reaches this age (in updates), it dies.
- *Strength* How strong an animal is in a fight.
- *Reproductive energy* When an animal has reached this energy level, it will attempt to reproduce.
- *Age of sexual maturity* The minimum age at which an animal can reproduce.
- *Gestation period* The minimum time interval (in updates) between two reproduction events of an animal.
- *Reproductive rate* The number of offspring per reproduction event.

3. Process overview and scheduling

An update of an Ecologia simulation is executed in the following order:

1. *Update grass density.*
2. *Update herbivores. For each herbivore:*
    - 2.1. *Check for death by old age or starvation.*
    - 2.2. *Reproduce if possible.*
    - 2.3. *Flee if there are predators nearby.*
    - 2.4. *Move to better grazing grounds if the local grass density is too low.*
    - 2.5. *Feed (unless after fleeing).*

3. *Update carnivores. For each carnivore:*
   - 3.1. *Check for death by old age or starvation.*
   - 3.2. *Reproduce if possible.*
   - 3.3. *If exhaustion levels are too high, rest.*
   - 3.4. *Otherwise, look for prey.*
   - 3.5. *If prey was found, move towards it and attack when close enough.*
   - 3.6. *If no prey was found, move randomly.*

Tiles, herbivores and carnivores are stored in arrays and updated sequentially.

4. Design concepts

Basic concepts. Two fundamental concepts in Ecologia are obviously food chains and predator prey relationships. Using the default state variables as given below, the model shows stable Lotka-Volterra dynamics emerging from individual foraging and reproductive behaviour. This system behaviour is one of the foundational principles of ecology; reproducing it was one of the primary development goals for the model. Other starting configurations can lead to other results, such as the extinction of one or both animal species.

Emergence. As stated above, Lotka-Volterra cycles are an emergent feature of the model. They are caused by density-dependent oscillations in resource availability for each consumer in the food chain. For example, the initial average grass density is very high, leading to an abundance of food for herbivores. However, the ensuing population boom places a high strain on the grass density, pushing it down and depriving the herbivores of their food again, causing the population to shrink until the recovery of the grass density initiates another cycle. Also, space acts as another limiting resource: as the herbivore population density rises, the growth rate slows as there simply is not enough space for new offspring.

Adaptation. Individual animals faced with scarce resources will attempt to move to an area with more resources. If they cannot see any better resource (more grass or a prey animal) within their field of sight, they will move at random until they do.

Objectives. Basically, an animal's goal is to maximise its reproductive fitness (number of offspring). In general, it will therefore try to maximise its energy, as a certain energy threshold is a prerequisite for reproduction. However, animals consider their own survival as more important than a short-term energy gain.

Learning. No individual learning takes place in the model. Nonetheless, if the mutation rate of a species is greater than 0, random mutations can affect its genetic variables. This can lead to (albeit limited) Darwinian evolution across generations, as new animals with better genomes outcompete others.

Sensing. Animals are capable of inspecting tiles within their range of sight. They can tell the grass density on such a tile, or whether it is occupied by a herbivore or carnivore.

Interactions. The only direct interaction provided for in the model is that of a fight between a hunting carnivore and a herbivore. Indirect interactions are based on competition for a resource, specifically for food and space.

Stochasticity. The outcome of a carnivore-herbivore fight is partially random (the other factor involved is the combatants' strength). Also, animals move at random if they do not have sufficient food resources in their vicinity. Lastly, mutations are based on a random change of a genetic variable.

Observation. Ecologia writes a log file with varying levels of verbosity (depending on the user's settings). This currently includes information on herbivore and carnivore population sizes and the average grass density, which are collected every update. These data are then used to produce population-time graphs for further analysis. At the highest verbosity level, every individual's genomic and lifetime data are written to file and can be inspected.

5. Initialization

By default, the world is initialized with the values shown in table 1. The values were chosen arbitrarily, then optimized to yield a stable ecosystem. All of them, except the meta-mutation rate, can be changed using the graphical user interface provided by Ecologia. (The meta-mutation rate can currently only be changed directly in the source code.) Alternatively, a configuration file can be used for initialization.

6. Input data

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

World variables		***Genome variables***		
Variable	**Value**	**Variable**	**Herbivores**	**Carnivores**
World size	{100, 100}	Mutation rate	0	0
Humidity	WET (+1)	Speed	2	3
Number of water tiles	10	Stamina	10	10
Initial grass density	100	Sight	4	4
Number of herbivores	200	Strength	10	11
Number of carnivores	50	Metabolism	10	18
Herbivore start energy	100	Age limit	150	200
Carnivore start energy	150	Reproductive energy	120	200
		Age of maturity	15	30
Meta-mutation rate	0	Gestation period	10	10
		Rate of reproduction	2	1

Table 1: Default state variable settings as configured in the source code.

7. Submodels

For implementation details, the reader is directed to the Ecologia source code, hosted on www.launchpad.net/ecologia.

Literature

Grimm, Volker, Uta Berger, Donald L Deangelis, J Gary Polhill, Jarl Giske, and Steven F Railsback. 2010. “The ODD Protocol : A Review and First Update.” *Ecological Modelling* 221: 2760–68. doi:10.1016/j.ecolmodel.2010.08.019.