Towards an Artificial Polytrophic Ecosystem

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Artificial Ecosystems

Ecosystems are modeled in disciplines ranging from ecology to art whether to produce accurate prediction tools or simply aesthetically pleasing environments. The computer science literature contains a number of works focusing either on plants (e.g. Bornhofen (2008)) or animals (e.g. Miconi (2008)).

This work lays the basis for a "Polytrophic" ecosystem that would exhibit a simplified food chain. The rationale behind this goal is to study the large amount of interactions between plants and animals observed in the natural kingdom (pollination, zoochory, etc.).

L-Systems proved to be powerful tools for encoding plant morphologies, yet their application to mobile creatures was more difficult, e.g. Komosinski (2003). In addition, black-box models such as GRNs, while flexible enough, were put aside due to their relatively high computational cost as well as their inability to produce intelligible genomic data. The directed graphs described by Sims (1994) (hereafter called 'graphtals') have been successfully used to generate complex yet functional body plans for animated creatures. However, despite their potential to be applied to plants, they have, to the best of our knowledge, not been so far. Nevertheless their expressive prowess and structural simplicity were deemed enough to model both the animal and vegetal kingdoms while allowing for insights into the mechanisms of evolution. This paper shows how graphtals can be used to generate plants which are growing from a seed in a physically simulated 3D world.

Model

Environment

In this work, plants are growing in a 3D environment composed of a flat ground, a light source and a simplified water cycle. Sun is designed as an infinitely far directional light whose position is a function of both night/day and seasonal cycles. These constraints should induce more robust behavior in evolved individuals as they have to find strategies to cope with unproductive night-time and low-angle light (during "winter") which would prevent most leaves from direct exposure.

The water cycle was modeled in two steps: First, rain patterns were generated pseudo-randomly (but consistently across evaluations) both in terms of occurrence and intensity so as to appear unforeseeable. Second, rain falls on the ground but is only accessible to plants once it is absorbed, at a slow rate, by voxels below the surface whose saturation level is rather low (2L/m^3). These levels increase linearly until the deepest layer, which behaves as a groundwater table. Moreover a portion of water is removed at each tick from the top (resp. bottom) layer to simulate evaporation (resp. water displacement). This aims at inducing two classes of behaviors observed in natural plants: large near-ground root networks to capture precipitations and digging tendencies to exploit deep water reserves.

Plant growth model

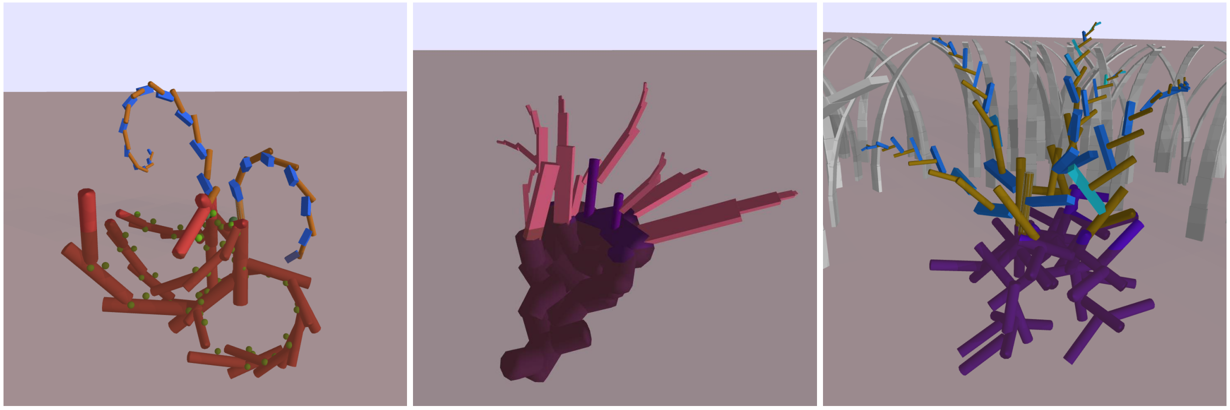
This work expands upon the original model by allowing each node to specify its shape (sphere, box, cylinder), skill (root, leaf), initial dimensions and anisotropic growth factor. Behavior is controlled by two tuples $A, S \in [0,1]^E$ with E the number of elements (water and glucose in this experiment). A models an organ balance between production and consumption: a value of 0 (resp. 1) indicates a source (resp. sink). S enables quiescent behavior by imposing a threshold below which no growth or budding actions can be performed.

Evolving plants do not require the bilateral symmetry present in the original animat experiments by Sims, links in this model instead use an 'effect' to generate multiple child organs at once (e.g. Radial($\mathbf{V}, N$) creates $N-1$ copies of the target organ uniformly rotated around a vector $\mathbf{V}$)

Metabolism

All individuals start from a seed, root and sprout. To maintain comparability between evolutions the seed is set to a spherical 2cm-radius organ saturated in both nutrients.

To survive, plants must draw water from the ground (using organs with the appropriate skill) and use a portion of it to generate a certain quantity of glucose in its leaves given by Eq. 1.



(a) Multiple sprouts (b) Grass-like (c) Upward growth

Figure 1: Various plant morphologies obtained by evolution[1]

$$k * \sum Surface_i * \mathbf{Light}.\mathbf{Normal_i} \tag{1}$$

Resources distribution is centralized to prevent unnecessary complexity, each organ receiving a portion relative to its size and its genomic parameter A. Organs consume part of their reserves as a function of their skill (e.g. 150% for photosynthesis and 75% for the roots). A negative balance in either nutrient or disconnection from the parent triggers the organ's death which deletes the individual and all its children from the simulation. A seed behaves like an organ but its death does not affect its descendants.

Experiments

In a first experiment, individuals were evaluated in an empty environment with a sunset every 100 ticks and 300-day years. The sun started at its apex position ($3\pi/8$) and went as low as $\pi/8$ during winter. Rain patterns provided an average precipitation of 787mm per year, two thirds of which occurred during the first half of the year.

The fitness, computed as in Eq. 2, rewarded glucose production in such a way that individuals were incited to stay alive the maximal duration of 2 years (N=60,000 ticks) and develop multiple leaves (see Figures 1a and 1b).

$$Fitness = \frac{2}{N(N-1)} * \sum i * G_i \tag{2}$$

In the second experiment, 100 hand-made grass blades were placed around the seed to simulate the competition for light observed in nature and stimulate vertical growth. This induced a size increase of the evolved plants in order to rise above the grass blades (see Figure 1c).

Conclusion and Future Work

One the most crucial natural resources not included in the present work is the effect of heat on the plants. While its impact could be manifold, e.g. on the transpiration rate or the speed of chemical reactions, it could easily be coded by genomes through a bell curve with a 'preferred' temperature and a tolerance range.

From a broader perspective, as our end goal is the emergence of complex ecosystems, this work provided a proof-of-concept for the use of graphtals in plant modeling as well as a few promising initial individuals to seed such a world.

Indeed, populating large non-uniform environments would allow for competition and speciation processes to occur spontaneously. Further evolution of the topological and meteorological parameters through a classical genetic algorithm would allow for comparison between the complexity of the generated plants and that of their world.

Finally, including motorized connections and heterotroph capabilities in the genomes while providing central controller, such as an ANN, would see the emergence of animals and close the food chain.

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[1]Movies of these plants and more can be accessed at `https://vimeo.com/channels/1221252`