Ecotone:
Nutrient Dynamics and the Emergent Behavior of Ecological Agents

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Abstract

We present a novel ecological simulation that explores the relationship between rational agents and their environment. Our goal is to simulate the basic elements of an ecology necessary to show how rational agents "evolve" to establish particular niches within the simulated ecological space. We describe our "reasoning" system which allows agents to evaluate actions based on two separate knowledge bases, both of which dynamically change throughout time as new information is sensed. Each animal stores knowledge about individual animals, which then allows them to make inferences about species as a whole. We have also developed components that simulate abiotic systems, such as the sun and wind systems, which cause nutrients to drift across the landscape.

Introduction

This paper describes Ecotone, a nutrient dynamics simulation which aims to explore how rational agents within a dynamic system evolve to occupy a particular niche within that system.

An *ecotone* is a transition area between two different ecological communities that exhibits competition between organisms common to both. The etymology of -tone is the Greek *tonos*, meaning tension. That is, it is an area where organisms are in the process of vying for resources and potentially in adapting to new niches. Our simulation is expressly concerned with the tension of unstable and initially random populations adapting or failing to adapt in competition with each other.

Ecotone is an extremely minimal model of an ecological system which nonetheless contain enough components to mimic complex multi-layered behavior. The ecological landscape consists of a grid of discrete cells. Each cell in the grid contains some amount of "nutrients". The nutrients are spread throughout the grid both through abiotic and biotic processes. For instance, a wind system will cause a certain portion of certain elements to be transferred into adjacent cells. More complex behavior occurs as the plants, the primary producers, photosynthesize sunlight and so deposit nutrients into the ecosystem. Secondary producers, herbivores, search out the richest areas of plant life. Tertiary producers, carnivores, hunt herbivores.

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Our model depends on the discretization of a landscape into a grid of cells, as well as the discretization of time into discontinuous increments. It also depends upon the conflation of nutrients at different levels into a small set, ignoring the many complex processes of how they are transmuted and how they flow through the ecosystem. We also conflate the rationality of the individual with the behavior of the group. These choices were made in order to be able to represent an ecology which of course is far too complex and too populated to represent visually. This project is currently in a prototype state. However, effort has been made to modularize various aspects of the simulation so that further aspects of the ecological system, both biotic and abiotic, may be "plugged-in" as desired so as to explore the effect on the system as a whole.

Previous Work

Models of complex ecological dynamics were devloped as early as 1963 by the biologists Rosenzweig and MacArthur. Their work examines the predation dynamics between a single predator species and its prey. They found boundaries of stability within this very basic system which, when overstepped, created the emergence of complex and potentially chaotic population oscillations (Rosenzweig and MacArthur 1963). Interestingly, one of the main goals of the paper was an attempt to create a visualization technique to graphically chart these systems. More abstractly, in 1970, John Conway created the "Game of Life" as a computational curiosity to investigate the emergence of complex behavior from extremely simple sets of rules (Gardener 1970).

In recent years, scores of systems across a variety of disciplines have been developed to explore the phenomena of complex emergent behavior that may arise from simple systems or rule sets. Relevant to our project, the nascent field of computational ecology aims to apply generative algorithmic techniques as a means to model aspects of real-world ecological systems. For instance, the application *Circuitscape* applies circuit theory to predict "patterns of movement, gene flow, and genetic differentiation among plant and animal populations in heterogeneous landscapes" (McRae et al. 2008). Another recent application, *Polyworld*, models the survival of species by creating a virtual landscape and populating it with various "animals", each with its own genetics, physiology, learning strategies, and neural systems. It encodes the intelligence of each animal using a reinforcement learning strategy via feedforward neural networks. Evolutionary behavior is simulated with genetic algorithms that select for a variety of traits such as size, strength, speed, and a host of parameters that define the neural networks, or intelligence, of each animal based on competitive pressures (Yaeger 1994). *Polyworld* has been used as a tool to evaluate passive and driven models of evolutionary bias towards ”forms and functions of greater complexity” (Yaeger, Griffith, and Sporns 2008).

Our work attempts to build on the themes described in the above research and applications.

Components of an Ecological System

From Wikipedia's article on Ecology: ”A central principle of ecology is that each living organism has an ongoing and continual relationship with every other element that makes up its environment. The sum total of interacting living organisms (the biocoenosis) and their non-living environment (the biotope) in an area is termed an ecosystem. Studies of ecosystems usually focus on the movement of energy and matter through the system.”

Abiotic and Biotic Components

Abiotic components of an ecosystem include all the non-living factors such as climate, topology, geology, et cetera.

Biotic factors include the various relationships between living organisms, which are interconnected within trophic networks which determine how nutrients are disseminated through the ecosystem to sustain life.

{ need to fill in this section... }

The Ecotone Ecology Model

The Ecotone ecology simulates a portion of these abiotic and biotic components. Ecotone is meant to model interconnected, multi-level systems. The Entire ecology is set up as a discrete grid upon which plants and animals can position themselves and move themselves continuously along the grid.

Nutrients

A main idea in ecology is that ecological systems are fundamentally systems that move nutrients around. The word ”nutrients” indicates a conflation of elemental matter at various levels of organization. That is, it refers most fundamentally to elements such as Nitrogen, Oxygen, Carbon, etc, but it does not specify *how* the elements are organized. That is, ”nutrients” refers equally to elements, compounds, molecules, proteins, and indeed organisms themselves. The dynamics of a nutrient system is the way in which these nutrients are spread throughout the ecological system, whether through wind, rain, water, or through being stored in plants and moved around by animals. To make an even simpler system, we have limited the number of elements we are tracking to Carbon, Oxygen, Hydrogen and Nitrogen. Although an attempt has been made to replicate various ecological cycles, they are not exactly realistic.

An Ecotone instance begins with a set of Nutrients distributed across the grid. Each grid square has a Soil object that contains (initially random) quantities of each Nutrient. Nutrients serve as an abstraction of abiotic matter with a role in an ecosystem. Whereas a real ecosystem might have thousands of different compounds containing Carbon, Nitrogen, Oxygen, and Hydrogen, that are consumed, modified and redistributed by agents of the ecosystem, Ecotone has only a few simple, abstracted elements called Nutrients.

The Sun

The sun is scheduled to move across the landscape at particular intervals. As the sun passes overhead a particular cell it becomes completely flooded with light. Plants that are in the cell are able to photosynthesize. In our minimal model, this translates to plants being able to transmute the sunlight into Oxygen. Our Sun mimics the real sun, making an appearance periodically, distributing energy across the Ecotone grid. In the currently model, Plants that are within the Sun's radient energy area accept Sun energy and use that energy to collect Nutrients from the soil. Without exposure to the Sun, plants die and do not reproduce, breaking the balance of life in Ecotone.

The Wind

Real ecosystems usually include a number of processes that distribute matter (including life and nutrients) across an ecosystem (i.e. wind, rain, agent interaction, evaporation, etc.). It is thought that these seemingly choatic systems are necessary for ecosystems to thrive (see carbon cycle, nitrogen cycle, etc). We modeled Wind and Rain in Ecotone. With these matter re-distribution processes, we hope to provide a continually varying landscape that mimics natural processes. Our Wind model is quite interesting. See figure below. {Describe in greater detail!}

Plants

Plants are living beings with limited reasoning ability. They are able to sense the nutrients around them and make decisions based upon the availability of particular nutrients.

Animals

Animals are living beings with the ability to reason effectively and to take more interesting actions, such as moving, hunting, evading. The knowledge bases described below are mostly concerned with the sensing and reasoning abilities of animals.

Agents within the Ecotone Ecology

Although any real system would include an extremely wide range of species that includes produces, consumers, and decomposers, for our purposes we simplify all life to two classes: animals and plants. Plants have the main ability of photosynthesizing light into nutrients. Animals have the ability to move. Additionally both plants and animals have an ability to reason using a base of knowledge that is developed through their experiences of the world.

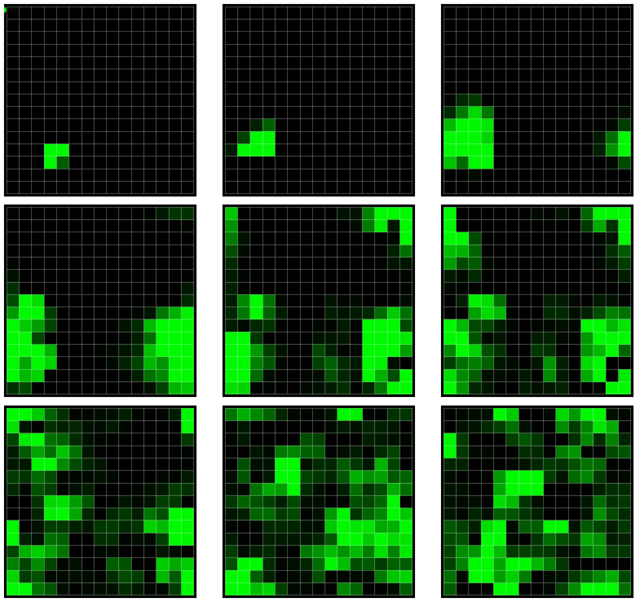

Figure 1: Snapshots of nutrient drift over intervals of 20 time units. An initial grouping of some element quickly disperses throughout the system.

The main goal of living being is to survive. At each turn, the plant and animal agents have to determine what actions to take that increase their chances of thriving and surviving. A plant has the following abilities: to breathe, to transmute sunlight, if available, into nutrients; to grow, and to reproduce. An animal has the following abilities: to breathe, to eat plants, if available; to eat animals, if available and strong enough; to reproduce; and to move. Each of these actions requires a certain amount of nutrients, but of course a combination of these actions also will directly or indirectly contribute to the availability of nutrients to the organism.

Another difference between plants and animals is in their range of sensing. Plants have only a limited ability to sense the abiotic components of their environment, including the nearby nutrients, and the sun and the wind. Animals on the other hand do not sense nutrients directly. Rather they have the ability to sense both plants and other animals. Based on these senses, Each organism builds up a knowledge base which they use to determine the best course of action at each turn.

Evolving Knowledge Bases

An animal stores a series of "sentences" describing the important parts of the world as it sees it.

Each animal has a current coordinate as well as a current direction that they are heading. From that position, they have a view range of a particular angle greater than and less than their current direction up to a particular distance. The animal is able to directly sense any plant or animal within that view range.

When an animal sees another animal it is checks to see if knows anything about that specific animal as well as if it knows anything about the species of animal. As an animal observes an individual animal it is able to infer further detail about that animal, which it can then use to evaluate its response towards it.

This evaluation uses the minimax algorithm to evaluate future states by assuming that other animals are also acting rationally.

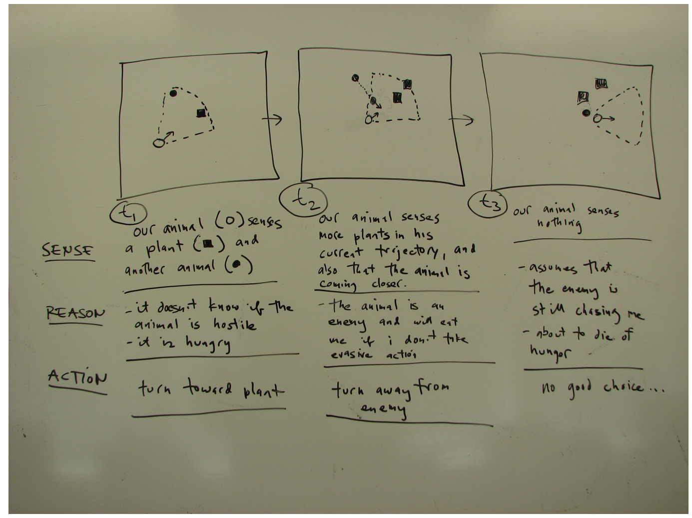

Figure 2: The rational movement of an animal (As) based on a dynamic knowledge base.

Given this awareness of other agents, each animal is able to decide what action to take, and more exactly how to take it. As an example, if an agent sees three hostile animals, but can infer that one of the hostile animals is not in active pursuit, then the agent will give less weight to the danger of that animal.

Specific Temporal Knowledge

Each animal stores temporal knowledge about every individual animal that it encounters.

If an animal senses another animal that it hitherto knows nothing about, then the only information it can determine is its position. If, at the next turn, the same animal is sensed again, then we now have further information about the animal's speed and turning range. If on a third turn, the same animal is sensed again, and the animal is moving closer, then that constitutes the further information that there is a probability that the animal is hunting the sensing animal. Similarly, if we are a predator hunting a particular species of prey then a temporal sequence of different sensing will enable us to make better decisions. The first time we come across it, our most rational choice is to move toward where we see the animal– Which of course is probably not where it will be at the next turn. However, once we have seen a second time then we have information about the way the prey moves, and can plan our next turn to head toward where we think the animal will be heading.

We store this information in a hash that maps the animal to a temporal node. By examining these nodes we can determine if there is immediate danger to avoid or prey to hunt. Even we don't see an animal during the current turn, we check to see if we can make a prediction about where it has moved based on our previous knowledge.

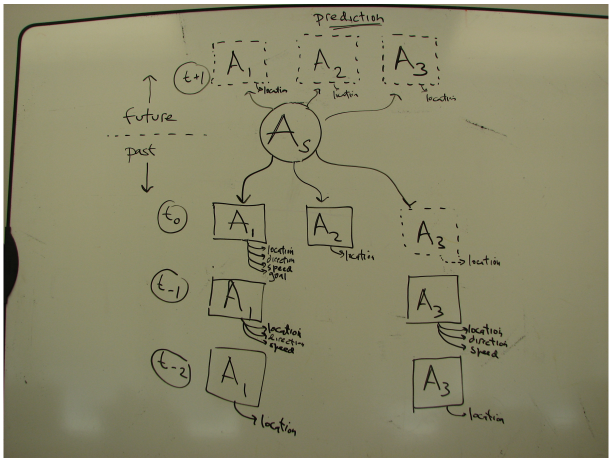

Figure 3: The specific temporal KB for a single animal (As)

General Asynchronic Knowledge

Each time an animal encounters an animal from another species, it is able to generalize about that species. For instance, if we were an herbivore and noticed that after three turns there was an animal clearly bearing down towards us, we could infer that this animal and all other animals from that species were hostile. Likewise, if we saw a predator hunt down one of our fellow animals, we would also be able to infer that animals of that species would probably hunt us down as well. This general knowledge can be updated with new experiences. For instance, if we have recorded that a particular species can can move 2 units in one turn, and then we see an animal of that species move 3 units, we both add to our temporal database for that particular animal and also update our general knowledge base for that species.

Proclivity Templates

In the absence of general knowledge, each species of animal is given a *proclivity template* which specifies the default assumptions the animal makes. For example, an animal may be given features of friendliness which will cause the animal not to take evasive action unless explicitly threatened. This proclivity may cause the animal to be eaten. On the other hand, an animal with a proclivity to be fearful may run be too frightened to get near clusters of plants and thus starve to death. Each of these proclivities is defined on a continuous scale. For example, an animal might be a .3 on the fearful/bold continuum, which means that in the absence of knowledge about a species the animal will have a 30 percent chance of taking potentially unwarranted evasive action. In the figure above, the rows with question marks indicate an absence of knowledge where the reasoning engine would default to the animal's proclivity template.

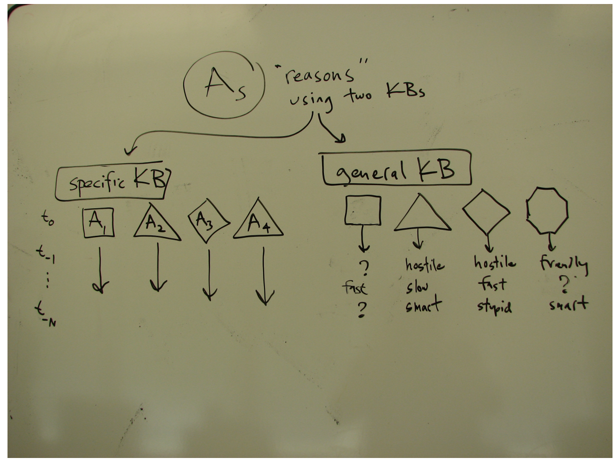

Figure 4: New information updates the the general KB which holds species level knowledge

Results

{This section is not finished. It will be ready in time for the presentation on Monday, Dec 8th.}

The goals of this project were to see if techniques from Artificial Intelligence could be valuably applied to questions concerning ecology, in particular the to see if we could coax our minimal agents to establish and occupy ecological niches. Moreover, we thought the addition of abiotic components, even minimal ones such as our wind simulation, would add a richness to the decision making process of our agents as it introduces and shifts nutrients throughout the landscape.

Future Work

Clearly an ecological simulation could expand in many areas. Since the application in highly modular, we hope to be able to add in further detail to describe an ecological system. This includes adding in other aspects of the biotope, such as topology, precipitation, et cetera, as well as explicitly modeling decomposers as an integral part of the biocoenosis.

The major aspect of this project that we have not yet implemented is the evolution of major traits directly from nutrients. That is, rather than pre-defining categories of organisms and their sensing and reasoning abilities, we had hoped to create a mechanism by which these abilities could evolve without predefinition. We hope to include this mechanism in a future version of Ecotone.

Finally, one of the major issues in ecology is what is termed "the scaling problem." That is, that systems show variability on spatial, temporal, and organizational scales (Levin 1992). Ecological processes that seem important to a particular patch of forest turn out to be inconsequential to the forest as a whole, or vice versa. The implication is that it is necessary... {finish!}

System Details

Ecotone is made up of two main software components, the reasoning engine and the visualization engine. The reasoning engine was custom built in Java 6 using concepts taken from the text book Artificial Intelligence: A Modern Approach, especially from chapters 7, 10, 11, and 12 (which describe logical agents and planning based on reasoning with knowledge representations) (Russell, Norvig, and Canny 2003).

Rather than creating a generalized logical framework for all types of agents, we created modularized mechanisms for the various classes of agents, each of which could ... The reasoning engine is quite fast at least with the small number of agents we are testing the simulation with.

The visualization was developed using the openGL graphics library and a custom animation library.

Our code is entirely open source and can be downloaded via anonymous checkout using subversion at https://svn.mat.ucsb.edu/svn/ecotone. The most recent source code can also be seen via Trac at https://svn.mat.ucsb.edu/projects/ecotone/browser/src/ecotone. Currently to build Ecotone you must link to the Behaviorism visualization framework library, which can be downloaded via anonymous checkout using subversion at https://svn.mat.ucsb.edu/svn/behaviorism.

References

Gardener, M. 1970. Mathematical games: The fantastic combinations of john conway's new solitaire game "life". *Scientific American* (223):120–123.

Levin, S. A. 1992. The problem of pattern and scale in ecology: The robert h. macarthur award lecture. *Ecology* 73(6):1943–1967.

McRae, B.; Dickson, B.; Keitt, T.; and Shah, V. 2008. Using circuit theory to model connectivity in ecology and conservation. *Ecology* 10:2712–2724.

Rosenzweig, M. L., and MacArthur, R. H. 1963. Graphical representation of stability conditions of predator-prey interactions. *American Naturalist* 97(895):209–223.

Russell, S. J.; Norvig, P.; and Canny, J. F. 2003. *Artificial Intelligence: A Modern Approach*. Prentice Hall, 2nd edition.

Yaeger, L. S.; Griffith, V.; and Sporns, O. 2008. Passive and driven trends in the evolution of complexity. In Bullock, S., ed., *Artificial Life XI: Proceedings of the Eleventh International Conference on the Simulation and Synthesis of Living Systems*. Cambridge, MA: MIT Press.

Yaeger, L. S. 1994. Computational genetics, physiology, metabolism, neural systems, learning, vision, and behavior or polyworld: Life in a new context. In Langton, C., ed., *Proceedings of the Artificial Life III Conference*, 263–298. Addison-Wesley.