BELIFE: TEACHING GREENHOUSE MANAGEMENT USING AN AGENT BASED SIMULATOR

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ABSTRACT

This paper presents the structuring ideas behind the development of a multi-agent system. This system, BeLife, is a simulation tool with teaching objectives: (a) it intends to educate the core concepts behind the management of greenhouses and (b) it aims at fostering the understanding of experimentation in this particular context. The paper also describes a framework designed to support the creation of multi-agent systems for virtual environments and discusses its benefits.

INTRODUCTION

Multi-agent systems are becoming an alternative software methodology for building large and complex systems where emergent properties result from the interactions of their small components. The increasing interest arises, mainly, from the fact that agent-based approaches are more and more robust and scalable. Now, instead of building MAS with a few agents, we are able to scale up to hundreds, thousands and perhaps millions of agents.

In fact, in domain areas such as biology or macro-economics, where mathematical models were generally used for simulation, agents are now becoming an alternative to the development of such simulation environments.

Apart from a purely engineering advantage, there are other advantages in adopting a multi-agent approach. In particular, when the simulation tool is designed to support learning (thus, embedded in a virtual learning environment), the use of agents can be beneficial: (a) being able to change the agents' characteristics in real time might promote experimentation; (b) the possibility to describe the behaviour of each agent and see the impact that different behaviours have on the whole society; and (c) the facility to create different learning applications with the same simulation package, thus allowing for different perspectives for learning the same concepts.

These advantages motivated the construction of BeLife, a multi-agent simulation tool and a learning application that help children learn about greenhouse management and related biological concepts through experimentation and collaboration. BeLife has been designed and is being implemented using an agents' building tool (ION-Framework) that allows the creation of agents, objects and properties of the environment in a fairly straightforward way. We will show how that is done for BeLife.

This paper is organised as follows. First we will present some work that relates to our goals in BeLife. Then we describe BeLife in generic terms and its context of application. After we will describe the software platform developed for building the agent's simulation (ION-Framework). Finally we will present briefly the concrete use of ION-Framework for the development of BeLife and draw some final remarks.

ECOLOGICAL AND PLANT GROWTH SIMULATIONS

This work is focused on the conception of a virtual environment that successfully simulates plant growth and development in a greenhouse scenario.

Biology simulations have been the focus of other researchers and therefore we could find some other applications that at some extend relate to our domain and approach.

Arborgames (Savage and Askenazi, 1998) and SimFor (SimFor, 2004) for example are systems that simulate forest dynamics and are used to support the management and decision of harvest policies. In a similar way we expect our users to be able to manage a greenhouse and decide about strategies to keep a balanced ecosystem.

The main goal of the BeLife users will be to maximize the crop production of the greenhouse. Similarly in BioBlast (BioBlast, 2004), a tool developed by NASA that gives the user the challenge to manage the production of some vegetable species in a space ship using some hydroponics techniques, the main goal is to maximize the production of food in order to sustain the space ship crew. Additionally BioBlast was built as a tool to be used in the high school biology classes.

With education as a main purpose we can also find systems such as FoodChain (FoodChain, 2004) that simulates a lake ecosystem with fish population and algae. The FoodChain system main goal is the education of ecological concepts and the sensitization for ecological problems such as the water quality in lakes and the impact of housing on the lake ecosystem balance.

We introduced in our simulation the presence of tiny agent populations that can infect the plants on the greenhouse, these populations behaviour can be inspired on simulations of micro organisms such as the BacSim (Kreft JU et al, 1998) microbiology simulation system.

One important feature of our system is that the simulation is being built in a way that its visualization and user interaction is achieved through a virtual environment; therefore the plant visual representation in the environment is an important issue in BeLife. Steinberg (Steinberg et al, 1999) proposed a very interesting approach to simulate the growth and development of plants in 3D virtual environments based L-systems and driven by a plant genetic code.

Although similar in many aspects to other simulation systems BeLife introduces some new features and challenges. By introducing the plagues in the greenhouse simulation we expect to increase fidelity of the simulation and bring new challenges to the users learning experience. Also simulations run on BeLife will be related to experiments made on real world greenhouses, and therefore presented in a virtual environment and in a long term time scale that can take several days of execution.

THE BELIFE APPLICATION

The BeLife application area is plant growth and plant diseases. These (plants and their attackers) will be part of an environment, build as a virtual greenhouse. The main idea is the simulation of several elements in the greenhouse and the study of the effects that a set of different types of plagues can have when they infest our plants. Thus, a MAS (BeLife) is being developed to simulate the life of the plants and of their attackers, as well as the influence they have in the environment (the greenhouse) and vice versa. The important agents in BeLife, are the plants (in our case, tomatoes and lettuces) and the plagues agents (a specific type of spider, a type of lizard, some species of fleas, one type of fly and some other worms). The environment has a set of factors that characterizes it (such as degree of humidity and luminosity among others).

The BeLife system will be used in a teaching context. In effect, it is being built specifically for teaching children the core concepts and techniques needed for greenhouse management through experimentation and collaboration. Thus, on top of the simulation tool, the BeLife system will support the learning of the main concepts of greenhouse management, facilitating the inspection of the plants behaviour as well as changing parameters in the environment and on the agents.

In relation to the overall background regarding the development of this particular teaching tool, BeLife is part of the COLDEX project. The COLDEX project aims at developing and using new IT approaches and computational tools to foster scientific experimentation, modelling and simulation in distributed and collaborative settings in an inter-cultural community of learners. (Milrad et al., 2003)

In fact, in the COLDEX project, the theme of greenhouse management will be taught using a real and a virtual greenhouse, taking advantage of both environments properties and aiming at learning synergies. The utilisation of the two distinct learning environments, the virtual and real greenhouses, follows a conceptual framework that emphasises the learning benefits of students interacting with models and simulations as well as building their own models (Milrad et al., in Press). Furthermore, BeLife aims at high level fidelity regarding the simulation of a real greenhouse. More specifically, the BeLife's high level learning requirements are:

- Teaching about greenhouse management - The system will teach students the conceptual issues and techniques needed for the management of a greenhouse. For example, the students will learn the relationships between environmental variables of a greenhouse and the growing of plants.
- Planning experiments in real greenhouses - The BeLife system will help the students towards the planning and development of experiments in real greenhouses. This issue is particularly important since doing experiments in a real greenhouse in a school context is not easy: (a) the manipulation of certain environmental variables is hard (such as changing the temperature in a greenhouse) and (b) the time factor associated with certain tasks makes it difficult to suit school scheduling (for instance, the observation of the actual growth of the plant makes the evaluation of alternatives a lengthy process).
- Collaboration - BeLife will foster communication and collaboration between learners. The tool will allow learners that have access to real greenhouses and learners that do not to find common ground for discussion

regarding the domain. In fact, it might be possible to observe the emergence of a virtual community with distinct learning roles. For instance, some learners might specialise running simulations with BeLife while others will be doing experiments with real greenhouses. Furthermore, BeLife will implement an explicit collaborative mode of utilisation. The collaborative mode will challenge learners to share a virtual greenhouse. Each learner (or group of learners) will have its designated space in the virtual greenhouse and will be responsible for planting a crop. Each group will be able to alter some environmental conditions parameters to maximise their crop. However, the challenge is to understand the implications of alterations and be able to cooperate and maximise the whole greenhouse productivity.

- Accommodate to blind learners - The BeLife user interface will suit blind learners, we aim at providing an interface that enables blind and non-blind learners to share information and collaborate in learning activities.

THE BIOLOGICAL MODEL

Being one of the important goals of BeLife to allow students to transfer the knowledge they build using the virtual world simulation to the context where they use a real world greenhouse, it is very important that our system is based on a scientifically accurate model that supports a very realistic simulation of events. For that reason, BeLife's plant model was done in cooperation with an agronomics expert. With her help we were able to identify the main variables and processes of greenhouse environment.

The most important elements of the greenhouse are the plants. They perform, regardless of its species, the following internal processes:

- *Photosynthesis* – biological process by which plants synthesise organic materials from inorganic ones (water and carbon dioxide), using light as an energy source;
- *Respiration* – process by which the plants obtain energy from the transformation of the organic material synthesised during the photosynthesis. This process leads to the growth of the plant;
- *Transpiration* – process of releasing water to the atmosphere through special cells in the plant's leaves. Transpiration is the main force of water and nutrient absorption from the soil and its translocation from the roots to the leaves.

Many species can be used in a greenhouse and, thus, can be modelled in BeLife. However, we will start with the tomato culture and later add the lettuce culture. They are well studied plants, commonly used as protected cultures to increase production and crop quality.

During period of a crop plants develop in several different phases having different needs and reactions to the environment in each one. In our model we consider the following phases:

- *Germination*: this is the beginning phase of a plant's life; it happens when a seed breaks its dormancy and begins to grow as a new plant.
- *Vegetative growth*: In this phase the plant reproduces its vegetation by increasing its leave area. With a higher leave area the plant can execute its vital internal processes with better results.
- *Florification*: After having a good supporting vegetation area the plant enters the florification phase in which the plant blossoms and its flowers may emerge.
- *Fructification*: in the fructification phase the plant fruits appear, in this phase the plant is ready to crop.

The students will have to understand these differences and change the environmental parameters accordingly to maximize the greenhouse's production.

The BeLife model defines six different parameters that were considered to be essential to the plant growth development and consequently crucial in a greenhouse management scenario:

- Light intensity – up to a certain point, more light intensity means more photosynthesis;
- Light exposition period – depending on the type of plant, this might be an important factor;
- Carbon dioxide concentration – increasing this value might help photosynthesis, but after a certain value it becomes toxic to the plant;
- Temperature – it's one of the most important factors and it's optimal value depends on the plant species;
- Water in the soil – although it doesn't directly affect photosynthesis, a short water level might reduce it through a lack of transpiration;
- Relative humidity level – because it has a strong influence in the respiration rate, the humidity level as a significant effect on photosynthesis. The optimal level depends on the plant's species.

In addition to the plants and the described environmental parameters, the students will also have to deal with plant infections.

The infections described in out model are a result of plagues of insects and worms that spread in the crop. We consider some of the usual plagues that appear in lettuce and tomatoes crops according to our agronomics expert. They include: a specific type of spider; a type of lizard; some species of fleas and a type of fly; and other worms.

The most common diseases are:

1. the *Mildio (Phitophora sp)* caused by the *Pulgões*;
2. the *Fusarium* caused by the *Mosca branca*;
3. the *Alternaria solani* caused by the *Alfinete*;
4. the *Verticillium albohatrum* caused by the *Aranhiço vermelho*;
5. and the *Botrytis cinerea*, caused by the *Roscas*.

The introduction of infections in our greenhouse brings an extra challenge to the students that have to manipulate the environmental parameters in order to maximize the greenhouse production and at the same time minimize the probability of plague manifestation.

IMPLEMENTING AN AGENT BASED APPROACH

In order to implement the agent-based approach, we are using an agent framework developed in the group GAIPS. This framework is being used for several other applications that involve virtual environments and agents (see for example FantasyA (Prada et al, 2003) or Papous (Silva et al, 2003))

The ION-Agents Framework

The ION Agents Framework (where ION stands for Interactive objects eNvironment) is one of the components of the global ION-Framework which was designed to support the creation of multi-agent systems for virtual environments. The main goal of this framework is to establish a clear interface between the intelligent virtual environment, their agents, and the visual components of the environment. This separation allows for reusability of the agents and even the graphic elements, thus fostering a quick prototyping for our systems.

In general, the ION-Framework has two distinct components, the ION-Graphics which deals with the visual components of the virtual environments and the ION-Agents that support the creation of agent based intelligent components (see Figure 1)

The ION-Agents is centred on the notion of abstract world, which defines the model of the environment. In the abstract world one needs to define the relevant entities of the world, their properties and their relations, how they are organized and in the case of intelligent agents which are their acting and sensing capabilities.

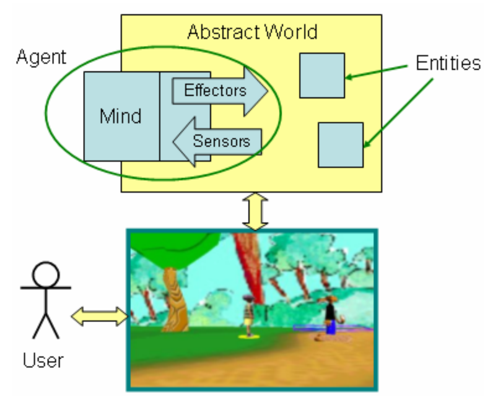

Figure 1 – The ION framework. The upper part shows the agent based definition of the environment that the lower part translates into a graphical representation to the user

We consider three different types of entities in the world: *objects*, *locales* and *agents*.

Objects are entities that can not manipulate the world. *Objects* are characterized by a set of properties that define their state (e.g. their colour) and can be part of relations (e.g. obj1 is on top of obj2).

Locales are entities that contain other entities. In addition locales define an awareness filter, which means that agents in one locale cannot perceive and act on entities that are on a different *locale*. *Locales* can be organized in a hierarchy; they can be placed inside other *locales*. This also creates a hierarchy on the *agents'* awareness, *agents* perceive and act on all *locales* that are children of the *agents'* current *locale*, but cannot perceive or act on the parents. *Locales* are also characterized by properties and relations.

Agents are entities that change the world state. They perceive the world by means of their *sensors* and act on the world by means of their *effectors*. The decision on what *effectors* to use is made by a control module, the *agent's* mind, which has the capability to process the perceptions and to start and stop the execution of *effectors*.

- An *effector* defines the possible actions of one *agent* in the world. These actions are processed in the world as changes in the entities properties and relations or by the creation of a world event. Each *effector* has some conditions that determine the failure or success of its execution.

- *Sensors* gather information from the world and transform it into perceptions that are meaningful to the *agent's* mind. *Sensors* build perceptions based on events that can be raised either by changes in the relations and property values or by *effectors'* performances.

Agents also have properties that define their public state and can be part of relations.

It is with the *sensors* and the *effectors* of the *agents* that we interface between the *agent's* minds (see Figure 1) and the *agent's* representations in the worlds. The minds of the *agents* can be built independently from the virtual world (provided that their *sensors* and *effectors* are implemented). It is the minds of the *agents* where we define their behaviour according to any agent architecture chosen.

Basically, the ION-Agents framework provides both the interface for *agents'* minds to be plugged in virtual worlds as well as it gives a structure and a set of functionalities to build the world model and associate it with a graphics representation.

The Greenhouse Model in the ION-Framework

The greenhouse model is based on the idea that each element of the greenhouse is either an agent in the virtual world or an object. The greenhouse may have different locales (for example we will have different areas for plantation and each area is managed by a group of students)

Regarding the three main concepts of the ION Agents framework (Locales, Agents, Objects) described in the previous section, BeLife is modelled according to the following description:

Locales

- Each greenhouse is a locale in the virtual world, although there isn't much interest in maintaining more that one greenhouse at any given time.
- The environmental properties (e.g.: light, humidity, temperature) are defined as the properties of the greenhouse locale.
- Each student is given a space (a sub locale) inside the greenhouse to plant his crop.

Agents

- One important agent is defined to control the general environmental parameters, the environment agent. It simulating the seasons and daylight changes. It can receive orders from the users through its sensors, and broadcast changes using its effectors.
- Each student is represented in the virtual world by an agent that retrieves all the relevant world data from its sensors and shows it to the user. Also, every user action is performed in the world through his agent's effectors.
- Each plant in the greenhouse is also represented by an agent that simulates all the complex internal processes and environment interactions. The plant processes are implemented as effectors, while the plant's mind controls the parameterization of the effectors according to the plant development phase.
- Each plague agent (e.g. spider or fly) is also modelled as a framework agent that reacts to the environment and harms the plants. The infection procedure is implemented by its effectors.
- Additional agents might be considered as features are being added to the system.

Objects

- Every world entity that is not an agent and has a visual representation is considered a world object. For instance, the greenhouse itself is a world object.

DISCUSSION

Although at an early stage of the project, we have however detected some problems. Some of the problems relate to the fact that the simulation must run during days, as if real time, in a server, from where students can inspect and modify some conditions and elements of the world in a collaborative manner. This approach although more linked to the reality, has to be complemented with other mechanisms and applications that allow kids to fast forward the time and see what happens if they change some parameters or some behaviour, still keeping the real simulation going on.

The second problem is to do with performance. Although scalable to many agents, there is clearly a degradation of the performance when we have many agents (in particular if we aim at hundreds of flies, or spiders…). This problem may be dealt with by simulating the flies with one agent for a set of lies and not a single one.

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