3D Archaeological Reconstruction and Visualisation: An Artificial Life Model for Determining Vegetation Dispersal Patterns in Ancient Landscapes

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Abstract

This paper describes a methodology and software engine for generating dynamic vegetation models for archaeological reconstruction and interactive visualisation, integrating the disciplines of Artificial Life (Alife) and Virtual Reality. The engine, based on the concept of emergence (a phenomenon in complex Alife systems), uses real botanical parameters, channelled through simple rules, in order to synthesise the dispersal patterns of natural vegetation communities as they grow, reproduce, and compete for resources. The foci for the development and evaluation of the Alife engine described relate to different scenarios in nature as may have existed during the Mesolithic period. Results from the study showed evidence of correlations between the artificial vegetation and their natural counterparts, demonstrating the feasibility of using such models in historical landscape reconstructions.

1. Introduction

Virtual Reality (VR) and Interactive 3D (i3D) technologies have benefited the scientific community in both simulation and scientific visualisation, empowering users with intuitive tools for investigating complex spatial and temporal databases and physical processes, both on- and off-line [1, 2]. In recent endeavours, researchers in archaeology and those involved in heritage conservation have adopted VR to excellent effect, applying and utilising the technology for education, interpretation and preservation of cultural and natural heritage [3]. The growing population of researchers in the Virtual Heritage Network, for example, [4] has witnessed many creative examples in the use of VR and i3D as tools purely for visualisation. In addition there have been a number of engaging attempts [5-7] at enhancing i3D creations with techniques from interdisciplinary research areas such as Artificial Intelligence (AI) and Artificial Life (Alife). In particular, the use of Alife techniques in virtual environments has provided a valuable and effective way for research within specific application areas where some researchers in the field of computer graphics seek to progress beyond visually compelling but essentially empty virtual environments to incorporate other aspects of physical reality that require intelligence or agents with characteristics of life [8].

In this study, we present a potential model for determining the spatial and temporal distribution of dominant vegetation types via the fusion of VR and Alife, focusing on modelling of Alife vegetation as an underlying technique with VR as a tool for visualising simulated data in a controlled virtual ecosystem. The study aims to explore new methods for archaeological landscape reconstruction and visualisation by experimenting with the concept of emergence associated with Alife [9, 10] and by addressing certain issues related to traditional methods utilizing Geographical Information System (GIS).

The target area of our study is a submerged ancient river valley in the Southern Basin of the North Sea (to the east of the United Kingdom) which, during the timeframe 10,000 to 7,000 years before present, was a land corridor connecting the British Isles to continental Europe. At this time, flora and fauna enjoyed a landscape untouched by the southern extent of glaciation, but one which would, in time, become submerged as the ice retreated. Recent (2003) seismic datasets have identified features of this landscape, including a significant river valley; these have been processed and static 3D reconstruction comprising high-quality digital renderings and interactive walkthroughs created for the purpose of visualisation and exploration [11]. Although the reconstructions
have provided a simple portrait of what the landscape might have looked like over 10,000 years ago, a credible and scientific representation of the different types of vegetation and their geographical evolution on the landscape has been elusive. In the early VR models, 3D library models of different plants were manually positioned on the terrain in accordance to subject matter experts in landscape archaeology and geo-archaeology. A more scientific approach would be to allow the different types of virtual vegetation, and their “communities”, to evolve, based on software tools that exploit a range of known biological, geological and environmental (climatic) parameters. The identification of Alife as an appropriate technique for such dynamic reconstruction exercises have led to the creation of the SeederEngine [12], a framework integrating both Virtual Reality and Artificial Life. Early evaluations [13, 14] of the framework and exercises conducted in researching how vegetation can be modelled as Alife entities have shown feasibility in its application for landscape reconstructions. Further experimentations with the model have not only demonstrated evidence of correlations between the model and natural vegetation patterns forming on landscapes, but have also provided an appropriate framework from which we can reconstruct a credible historical representation of the river valley discovered during the early analysis of the seismic data described earlier, and today referred to as the Shotton River Valley, after a famous British geologist.

The following section summarises some of the historical research related to this field of endeavour. In Part 3, the methodology of modelling artificial life vegetation agent and its ecology is presented. Part 4 evaluates the outcome of the model and finally, we conclude with the contribution and future directions of research including the extension of the model into the new domain of Serious Gaming [15] in marine life for scientific research, discovery, and visualisation.

2. Related Research

The integration of what Chapman and Gearey call a ‘processual’ and ‘sensual/experiential’ approach in the study of prehistoric sites and landscapes is uncommon and, therefore, the potential synergy that might result from closer integration often remains unrealised [16, 17]. Whilst a scientific approach, incorporating geological and ecological variables, is indispensable, it has become recognised that the subtleties of embodied space, essentially the experience of ‘being in the world’, is important in the interpretation of the spatial relationships between monuments, spaces between monuments and the routes that connect them [18]. The culmination of research efforts in computer graphics and VR over the years have addressed issues relating to various aspects of information visualisation, namely the interactivity and dynamics of visual representation of simulated data, enabling researchers to interact with data in 3D space by ‘being there’, thus augmenting the real-time experience and, it is claimed, the ‘believability’. Although i3D technologies have evolved in recent years to become both affordable and accessible [15], conventional methods in the interpretation of prehistoric landscapes [17, 19] or the prediction of
current or future ‘natural potential vegetation’ [20, 21], although useful, remain largely a process of assessing visual patterns in statistical visuals of two-dimensional space. Furthermore, these approaches, typically hosted in a Geographical Information System (GIS), generally do not take into account the dynamics of the lifecycles of plants (i.e. growth, competition, reproduction and seed germination of the individual species of plants).

Over the past decade, scientists’ perceptions of complexity in global systems have changed [9, 22-24]. Moreso than ever before, scientists are using decentralised models, self-organisation, self-assembly and other metaphors to describe the phenomena they observe in the sophisticated world. It is well known that many complex matters or behaviours emerge from the local interaction of simple entities or rules. For example, most people assume that birds follow a leader in the flock. However, “there is no special ‘leader bird’. Rather, the flock is an example of ‘self-organisation’. Each bird in the flock follows a set of simple rules, reacting to the movements of the birds nearby. Orderly flock patterns arise from these simple, local interaction” [24]. In a simulation [25], flocking behaviour emerges from three sets of simple rules – separation, alignment and cohesion. In another study [26], slime mould, composed of distinct, separate single-celled units, was found to be capable of finding the shortest possible way through a maze via collective behaviour. Already, researchers have started using the simple rules in nature to solve problems, such as those inspired from insect swarms [27]. The science of Artificial Life [10] aspires to investigate these complexities in order to understand and, perhaps via the knowledge acquired from the studies, ‘extract the regularities from incidental and irrelevant details’ [9] in order to synthesise natural life, or apply the distilled principles for problem solving.

One of the fundamental concepts in Alife is emergence [9]. Mihata [28] defined emergence as “the process by which patterns or global-level structures arise from interactive local-level processes.”, and “this ‘structure’ or ‘pattern’ cannot be understood or predicted from the behaviour or properties of the component units alone.” The natural distribution of vegetation communities on landscapes cannot be understood by studying individual plants. It is the local interaction of many species of plants with the extra-local ecological factors that determines the formation of landscapes. It is this concept that we aim to explore in modelling vegetation for the reconstruction of ancient landscapes.

Literature in vegetation modelling related to Alife is scarce. A survey revealed only a handful of articles [29-31] of which only several [32, 33] are useful for simulation in large landscapes. This is, of course, to be expected as the science of Alife is relatively new for addressing our particular direction of research. A related model [32], whilst claiming to exhibit properties of growth, decay, and energy transfer reminiscent of a simple ecosystem, presents a somewhat primitive solution from an Alife perspective since it does not support plant growth or interaction between plants and the environment [8]. A closer model is Lange et al.’s [33] approach, which uses a growth simulator within an abiotic environment with only two input fluxes, such as energy and a growth-limiting nutrient. The actual growth of each tree in Lange et al.’s method is derived from local competition for energy and nutrients. Evolutionary effects are included by random mutations of parameters related to height growth strategies of individual trees. Our model contrasts with Lange’s approach in the inclusion of a generic model of customisable vegetation lifecycle that corresponds to different vegetation types (trees, shrubs, herbs, grass,
3. Methodology

In the artificial life context, there are at least three methods for modelling vegetation using the bottom-up, decentralised approach. One method is to model the plant from the interacting cells forming its structures; another [29-31] is to model the intermediate plant’s vascular architecture and its growth and interaction within a localised position. The third approach is to model the plant as a reactive agent - a complete unit that responds to ecological factors in order to determine the local and global patterns the plants form in landscapes. In this research, we evaluate the third approach as it is more suited to our problem domain.

We illustrate a generic model of vegetation used in our study in Figure 1. The artificial plant is modelled based on the characteristics of its natural counterpart, germinating from a seed before beginning its lifecycle of growth, competition, reproduction, and death. The Alife entity possesses sensors for sensing ecological and seasonal changes, both reacting and adapting to variations based on customisable properties and preferences stored as XML structures (which includes seed germination and adaptability information of the plant towards different environmental conditions [13]).

In the series of discreet time steps running from a calculated monthly average of ecological factors, each plant senses its environment and identifies plants in close proximity for competition. The competition is local and based the competing plants’ canopy, leaf density, height, and vegetation types. The form of the plant (trees, bushes, and undergrowth) and the distances between them is taken into account. The following rules describe the synthesis of plant life:

1. Plants reproduce in their assigned season.
2. Seeds are dispersed in different directions and dispersal agents are simulated by dispersing the seeds further.
3. Seeds have a period of dormancy before suitable environmental conditions cause it to germinate; seeds expire if they do not germinate within an assigned period of time.
4. Plant tolerance/adaptation to ecosystem factors is based on an upper, ideal and lower value [13]. Different plants have different adaptations.
5. Plants compete for availability of sunlight, space and nutrients based on environmental conditions and the sizes and shapes of competing plants.

The individual fitness of plants can be studied via a plant indicator in the virtual environment revealing information at the local plant level relating to effective sunlight, nutrient, altitude, and so on (Figure 2).

Synthesising dispersal patterns of vegetation also requires knowledge pertaining to the environment in the target landscape in order to provide equal opportunities for plants suited to different habitats to thrive and compete. Conditions for simulating the British Mesolithic landscape are readily obtainable [35, 36]:

1. The global environment conditions of the landscape – sunlight, temperature, moisture, nutrients, elevation and carbon dioxide.
2. The local environment conditions affected by plants in close proximity – effective sunlight, moisture and availability of space.
3. Temperature-elevation ratio.

In accordance with the concept of emergence (Figure 3), we model the formation of communities of vegetation on the landscape based on the local interaction of species affected by ecological variables. The following section describes the outcome of our studies.

4. Experimental Observations

A simulation of climatic changes affecting vegetation distribution and migration patterns using the Alife model has been demonstrated [14]. Using the same model, the reproduction, distribution, and competition of vegetation species in compact landscapes has also been studied [13]. The experiments covered in this section further demonstrate the preferences of different vegetation species in relation to resource availability in the ecosystem and dominance of vegetation types over a span of 500 years.

A terrain measuring 150m² and 50m at the highest point of the landscape relative to the river was “sampled” from the Shotton River Valley virtual environment. Equal numbers of seeds belonging to
Figure 4. Experimental scenario – a Mesolithic landscape

three species of vegetation – Pine, Hazel, and Willow – were equally distributed across the landscape. The environmental setting simulates a typical Mesolithic landscape in the North Sea region. Virtual time is discrete and runs in sequences of months with seasonal changes and ecological variations. In the simulation (Figure 4), as the virtual years progress, seedlings belonging to the species begin germinating and growing. At year 71 the landscape has a healthy population. Willows began forming near the river bank where the hydrology is ideal. This reflects the Willow tree’s preference in the natural world. Pine and Hazel appear to have an equal distribution across the landscape. From years 116 through to 179, the Pine and Hazel begin occupying most of the spaces, ‘herding’ the Willow towards the lower right corner of the river bank. At year 250 the Willow species disappeared entirely from the terrain. At year 500, the
Pine species dominates the landscape. As observed, each species’ characteristics and their strength and preferences towards a typical environmental setting is apparent. The preference of the Willow tree is observable near the river banks. The Hazel appeared to spread across the landscape faster than the other species, occupying spaces and competing with other plants. The Pine is a naturally slow-growing tree, even though its growth timeframe is lengthy, spanning hundreds of years, its characteristics, adaptability, and height makes it the dominant species in the later stages of this particular landscape setting.

An observation of the same landscape planted only with the Willow species is drawn with a red border. In comparison with previous observations, at year 282 the Willow species has a healthy population near the river banks without competition from Pines and Hazels.

5. Conclusions and Future Work

In this article, we attempted landscape archaeological reconstruction and visualisation with what we believe to be a novel approach. We have attempted to integrate the new science of Artificial Life with virtual reality to produce a dynamic, visually-rich tool for investigating the principles of emergence in nature and generating digital solutions for predicting vegetation terrain colonisation. By using VR and i3D technologies, we extend the information visualisation capability of the landscape reconstructions that will enable an enhanced environment for archaeological investigation and interpretation. Thus far, the model has demonstrated its potentials in various studies, mimicking its natural counterparts with real botanical properties channelled through simple sets of rules.

Our future research plans aim to apply the research described above to a more modern-day scenario – the colonisation of artificial subsea reefs by marine life. In support of this, and in collaboration with the UK’s National Marine Aquarium (NMA), we are currently extending and modifying the SeederEngine research to provide predictive visualisations of what one particular reef (the scuttled Royal Navy vessel, HMS Scylla, Figure 5) might look like tens of years (and longer) into the future. It is our eventual aim to assess the impact of possible global climate changes on the sea and to model other factors, such as the effects of pollution or other short-term environmental variations. The project involves NMA subject matter experts, particularly in respect of the marine flora and fauna that will eventually inhabit the reef, their growth and reproduction patterns, their responses to subsea environmental changes (pollution, temperature, etc.). It will be possible to collect regular validational information from the reef over time (via subsea webcams or regular dives on the reef using remotely operated or manned submersibles).

Currently, an optimised low polygon 3D model of the Scylla has been created (Figure 6) and algorithms are being developed from extensions of the SeederEngine to accommodate artificial marine life forms. At present, data is being gathered for an early investigation to visualise the outcome in a real-time virtual environment.

Acknowledgements

We wish to thank Prof. Vince Gaffney, Director of the Institute of Archaeology and Antiquity, The University of Birmingham for his assistance in providing the original seismic datasets of the Shotton River for our study.