An Agent-Driven Virtual Environment for the Simulation of Land Use Decision Making

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EXTENDED ABSTRACT

The research outlined in this paper seeks to better understand land-use change decisions in a rural context. The project utilises the capabilities of virtual reality technology and agent-based modelling to create a virtual environment in which land-use change decisions can be made.

It is anticipated that the immersion of a user in a virtual environment will enable the study of land-use change decisions similar to those made in the real world. Experimenting within a laboratory environment provides advantages such as control over external variables and direct observation of their impact on land cover change.

The virtual environment is comprised of two networked computers, one running a parcel based agent-based model (ABM) within a geographic information system (GIS) interface, and the other controlling a visualisation of the landscape. A server links the two components, enabling real-time updates in the visualisation to reflect the land-use decisions made by the land manager agents in the GIS.

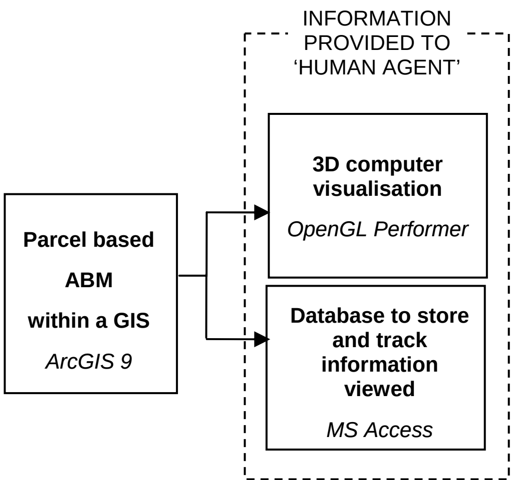

Figure 1. The virtual decision-making environment framework

A human decision maker operates within the virtual environment, making land-use choices that are influenced by the actions of neighbouring computer driven agents.

Conditions in the simulated environment can be controlled and the subsequent land-use decisions observed to determine the influence of different drivers on land-use decisions. Annual fluctuations in external factors such as climate change and commodity prices are accessed by the human user in the form of graphs and tables stored in a Microsoft (MS) Access database.

Observations of land-use decisions made within the virtual environment will lead to an improved understanding of the factors that are taken into account when making such decisions. For example, icons showing environmental quality can be displayed in the virtual environment to indicate the environmental impact of land-use choices. These can be switched on or off in different simulation runs to better understand their effect on the human user's future land-use decisions. In addition, the information viewed by the human user in the MS Access database is tracked to monitor the type of information that is used to arrive at a land-use decision. The effect of individual variables on the land-use decisions can be seen by gradually introducing information about different factors into the decision-making environment.

The improved understanding of land-use decisions that will result from this investigation could be used in the future to calibrate ABMs of rural land use. This will in turn allow for the investigation of potential consequences of land-use policy under varying conditions with greater confidence in the generated outcomes.

A visual comparison of possible landscape scenarios will provide a valuable tool for planning professionals in evaluating land-use policies and for engaging the community in the planning process.

1. INTRODUCTION

The environment in which rural land-use decisions are made is complex. A range of economic, environmental, and social factors can inform and influence a land-use decision. This paper outlines the development and planned application of a system that is designed to investigate how individuals interpret these factors when making land-use decisions.

The system has been developed on the understanding that a human user is more likely to make realistic decisions when operating within a realistic environment. The system, consisting of an agent-based model (ABM) linked to a computer visualisation, enables the human user to access relevant information, interpret this information, and make decisions, in a virtual world.

Within the environment, external variables can be controlled, and decisions observed, to better understand the impact of specific variables on land cover change.

2. HUMAN DECISION MAKING

2.1. Techniques for Investigating Decision Making

Several methods have been developed to better understand how people make decisions. An understanding of human decision making requires knowledge of the preferences that motivate individuals to select a particular option. Methodologies to derive this information include:

- *Stated Preference:* Stated preference techniques involve asking participants to rank a set of options in order of preference, or to select a preferred choice from a set of limited possibilities. From this information preferences for individual factors are derived.
- *Revealed Preference*: In contrast to the abstract environment in which stated preference experiments are generally undertaken, revealed preference studies involve observing the collective choices made by people in the real world. This information is then interpreted to reveal the underlying preferences that individuals have for different factors. While this approach overcomes some limitations of stated preference techniques, there is some debate over the validity of the underlying assumption that individual preferences can be derived from observed choices (Von Auer, 2004). For example, consumer choices in a real world situation may be influenced by variables that cannot be controlled or accounted for in a revealed preference study.
- *Experimental Economics:* A growing research area is experimental economics. In this approach, researchers overcome the limitations of both stated and revealed preference studies by creating choice experiments in an environment in which variables can be controlled. Through a series of repeated trials in a laboratory environment, the assumptions underlying economic theory can be tested, and the preferences or strategies of participants either controlled or measured (Roth, 1995).

2.2. Decision Making in a Complex Environment

Underlying much economic theory is the notion of rational choice; the idea that individuals will make choices that will be of maximum benefit to them. Implicit in this theory, however, is that individuals have access to all of the information needed to arrive at an optimal decision. It is then assumed that individuals use this information to choose the alternative that provides the greatest value for them within the given scenario. However, the real world does not generally provide the conditions required for this theory to hold true (Ostrom, 1998). This is certainly the case for the rural decision-making environment.

As Stoorvogel, et al. (2004) highlight, a single land-use change decision is influenced by a variety of factors acting at a range of different scales. For example, the availability of labour and the farmer's personal objectives will influence him/her at the individual level, while market trends and government policy will be drivers of change at a broader scale. The complexity of the decision-making environment limits an individual's ability to make ideal choices (Swait & Adamowicz, 2001). In addition, the capacity to process relevant information varies with each individual, causing inconsistencies in the choices that are observed (Swait & Adamowicz, 2001).

A further cause of irregularity in decision making is the possibility that information on these influencing factors may be scarce or incomplete. This uncertainty hinders the individual's ability to make an optimal land-use choice.

Accordingly, land-use decisions contradict many of the assumptions that underpin the theory of rational decision making. The result of this is seemingly 'irrational' decision making behaviour.

3. DEVELOPMENT OF THE VIRTUAL DECISION-MAKING ENVIRONMENT

The complexity of the rural choice environment not only impacts on an individual's ability to choose rationally, it also brings unique challenges to researchers seeking to better understand this phenomenon.

The development of a virtual environment to represent the rural environment enables us to investigate individual decision making in a complex setting. The system consists of two networked computers, one running an ABM operating within a geographic information system (GIS), and the other running a computer visualisation displaying the land-use changes made in the GIS (see Figure 1).

The ABM is based on the FEARLUS model developed at the Macaulay Land Use Research Institute (Gotts, et al., 2003). The FEARLUS model has been converted to a vector rather than grid format to allow for the representation of actual parcels of land (Zhang, 2004).

The computer visualisation of the landscape was created as part of a project undertaken by Stock & Bishop (2005) to allow for exploration of landscape changes in a community workshop scenario (see Figure 2). The virtual environment is displayed on three rear-projected screens. The screens are set-up to provide the user with a 135 degree field of view, ensuring a high level of immersion at a distance of up to five metres (Stock & Bishop, 2005).

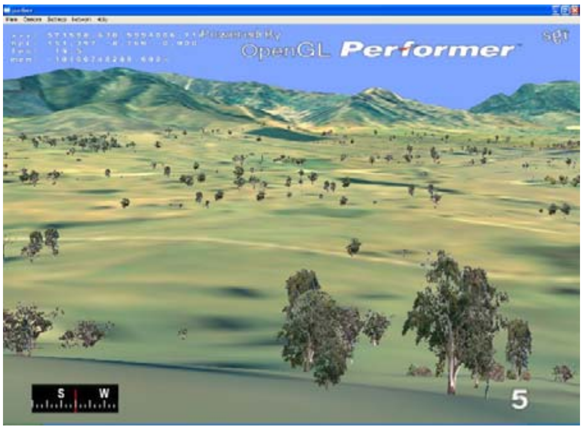

Figure 2. Computer visualisation component of the virtual environment

Within the virtual decision-making environment, agents select a land use for their parcel/s of land each year based on a range of biophysical, climate and economic factors. With each iteration of the model the annual average rainfall value and commodity prices are adjusted, and the yield of each parcel and corresponding agent's wealth is updated.

A human user is assigned a parcel of land, and effectively becomes 'an agent' in the system (see Figure 3). Annual land-use changes made by the computer and human agents in the GIS are updated in the visualisation in real-time. The human user can navigate around the environment and observe the land-use choices of neighbouring computer agents, which may influence the individual's decision.

The virtual landscape in this system provides a decision-making environment similar to that which a real farmer would observe. A farmer does not make a land-use decision in isolation, but is able to observe the behaviour of surrounding farmers and make land-use decisions accordingly. Our system provides this opportunity to the human participant.

Additional information relating to commodity prices, land suitability and the success of neighbouring agents is provided in the form of a Microsoft (MS) Access database. The information viewed by the human user is tracked within this database to allow for later analysis (see Figure 4).

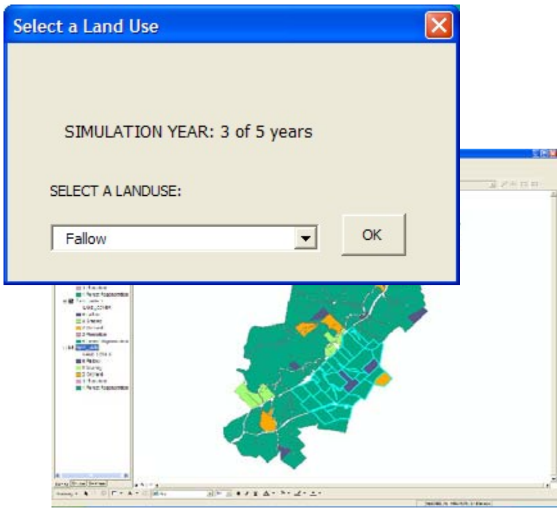

Figure 3. The ABM running in ArcGIS – request for human user to make a land-use choice

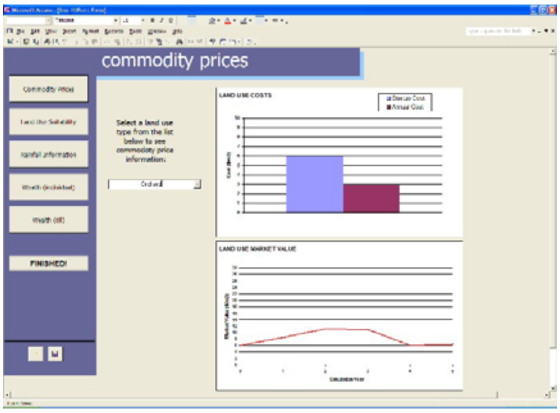

Figure 4. Information available to the 'human agent' stored in MS Access

To best understand the capabilities of the virtual decision-making environment, it is important to see how each component has been developed and used over time.

3.1. Agent-based Modelling

ABMs generally incorporate both the biophysical and human factors that combine to cause land-use change over time. Assumptions about decision making are used to develop simple rules that dictate the behaviour of agents and their interactions. An ABM is run over a series of time steps, with the accumulation of individual decisions leading to the emergence of observable patterns at a wider scale.

Deadman, et al. (2004) demonstrate the significant results that can emerge through the development of simple decision rules. Their ABM LUCITA (Land Use Change in the Amazon) is based on four key factors relating to household dynamics and land quality. The model yields similar land-use patterns to those observed via remote sensing in a section of the Amazon rainforest over a period of thirty years (Deadman, et al., 2004).

In the context of rural land-use change, the decisions made by individual farmers lead to observable patterns at the landscape level. Several researchers have shown the potential of agent-based modelling as a tool for representing and understanding this process (Evans & Kelley, 2004; Huigen, 2004; Manson, 2000).

ABMs can be divided into two categories – uncalibrated models that can be used to explore the principles underlying a system, and calibrated models that can be used for prediction (Batty & Torrens, 2001). The first category seeks to gain a clearer understanding of the processes leading to the observation of some phenomenon, and may use generic agent rules to investigate general trends.

Models of prediction require some grounding in reality. For example, forecasting the potential consequences of implementing land-use policy requires an understanding of the likely decisions that actual land use holders will make under varying conditions. In this case, computer agents are used to represent individual human decision makers.

A discrepancy exists for models of prediction, between the rational computer agent and the irrational human that the agent represents. A defining characteristic of most ABMs is the assumption that agents make rational decisions. For models of prediction, this principle can undermine an ABM's effectiveness in representing human decision making. As Arthur (1991) highlights, the development of ABMs that are calibrated using information gained from real human decision making will "furnish predictions based on *actual* rather than idealized behaviour" (Arthur, 1991, p353).

3.2. Integrating a Human Agent

Researchers have recognised the limitations of representing irrational humans with perfectly rational agents. Attempts to calibrate ABMs by integrating human and computer agents in the same model have shown promising results. Pingle & Tesfatsion (2001) have experimented with computer agents and human participants to investigate the role of a non-employment pay-off on the relationship between employers and employees. While their research found some similarities in the behaviour exhibited by the computer agents and human participants, the computer agents behaved in a significantly more coordinated way than the human participants.

Integrating human and computer agents tests the validity of the assumptions underlying agent-based modelling. Comparisons between real and simulated decision making have identified several anomalies that need to be accounted for if computer agents are going to accurately represent human decision making in the future.

3.3. Visualisation

Comparisons between human and simulated land-use decision making is difficult due to the complexity of the environment involved. Virtual reality technology can assist in overcoming this problem by representing this environment to a human decision maker in an accessible and familiar format.

While they are by no means a perfect replacement, computer generated visualisations have been shown to illicit similar responses as those made in the real world. In a comparison of responses to a real and simulated urban environment Rohrmann & Bishop (2002) found that respondents perceived the computer generated environment to be a valid substitute for the features presented. Similarly, in a visual comparison of a series of photographs and corresponding computer simulated images, Bergen, et al. (1995) found moderate to high correlation between mean ratings for the two modes of presentation.

The level of detail in a computer simulation adds to an individual's ability to relate to the scene being presented (Appleton & Lovett, 2003). The more realistic a computer generated visualisation, the easier it is for people to imagine the real environment that is represented. Following this it is assumed that if the visualisation is adequately representative then individual responses in the virtual environment will correlate with the choices that would be made in the real world.

4. SYSTEM DESIGN CONSIDERATIONS

4.1. Context for Decision Making

The context in which decision making takes place impacts on the choices observed. Swait, et al. (2002) highlight the need to incorporate context into choice experiments to ensure that their effects are considered when deriving preferences from observed results.

With regard to land cover change, the context in which decisions are made is integral to the observed individual land-use choices. The system outlined in this paper aims to enable the observation of land-use choices that are indicative of decisions made in the real environment. Hence, the context for these decisions needs to be the same in the virtual and real environments.

Context has been accounted for in this system in several ways. Firstly, the agents in the model add social context to the decision-making environment (Bishop, et al., 2005). Observing the land-use choices made by neighbouring agents may influence the land-use choices of the human participant.

Economic context is incorporated into the system through the use of commodity prices and measures of wealth. The market value for each land-use option fluctuates annually within the system. An MS Access database provides the user with this information, as well as graphs showing the annual wealth of the human compared to that of neighbouring agents. The human user interprets this information to reach a land-use decision.

Icons indicating the environmental impact of the land-use choices made can be displayed in the virtual environment. Indicators showing the influence of land-use decisions on factors such as water quality, salinity and habitat provide environmental context in the virtual environment.

4.2. Provision of information

A valid comparison between computer agents and a human decision maker is reliant on participants operating under the same conditions (Duffy, 2001). The human user needs to have access to the same information as the computer agents to allow for comparisons between their decision making behaviour.

The computer agents in the model can employ one of two strategies; imitation or initiation (Zhang, 2004). An imitator agent selects a land use by copying the land-use choice of the most successful neighbouring agents within a given radius. In contrast, an initiator agent selects the most suitable land use by matching the characteristics of the land parcel and the conditions in the simulated environment with the ideal conditions specified for each land use.

The human agent can use either of these strategies, or devise one of their own, to arrive at a land-use decision. The human agent is able to explore the virtual environment and observe the land-use choices of agents within a similar radius as the imitator agents. An MS Access database provides the same information to the human user that is accessed by the initiator agents. Tables of land-use suitability and graphs of annual rainfall in the simulated environment can be used by the human agent to select the most suitable land-use for their parcel of land. The design of the ABM means that computer agents cannot select a land-use type that is unsuitable for their parcel of land. This is not the case for the human agent however. If the land-use type selected for the human agent's land parcel is not suitable therefore, the yield for that year is set to zero.

Commodity prices fluctuate each year within the simulation, and the yield of each land parcel and wealth of each agent are updated accordingly. The level of profit a computer agent aims to make is determined by an aspiration threshold value, which is randomly determined at the start of the simulation. The wealth desired by the human agent is determined by the individual participant. The database provides the human agent with information on their own wealth in each year of the simulation, as well as a comparison with other agents. Graphs showing market values of the available land uses are provided within the database. Access to this information enables the human user to determine the profit they hope to make, and to select a land use to match this accordingly. For example, if the human agent is not satisfied with the yield from their parcel of land they may be willing to take more risk with their land-use choice by selecting a land-use type with the possibility of high returns.

5. CONCLUSIONS

In rural areas the decisions made by individual farmers lead to observable patterns at the landscape level. It follows therefore that sustainable land-use management at the regional scale can be achieved by targeting policy where land-use decisions are being made – the individual. For this to be effective, a thorough understanding of how individual decision makers respond to varying conditions is required.

The system described in this paper aims to do this through the use of computer visualisation technology to create a familiar environment in which decision makers can operate. The addition of agent modelling capabilities adds a social context to the system, providing the human user the opportunity to observe and potentially mimic the behaviour of neighbouring agents. Fluctuating market levels and environmental indicators add economic and environmental context to the decision-making environment.

Some potential lines of enquiry using this system include:

- How do individuals utilise the information available to them to arrive at a land-use choice?
- How does the provision of information impact on the decision maker's willingness to take a risk with their land-use choice? For example, if a farmer sees that he/she is not generating as much wealth as neighbouring agents, will this impact on the land-use choice he/she makes?
- Are future land-use choices influenced by knowledge about the environmental impact of past land-use choices? Is the individual's response different if separate environmental indicators are provided for the human and neighbouring computer agents?
- How do land-use change decisions differ when an individual has the opportunity to discuss their options with others?

Our system provides a platform for testing the potential consequences of land-use policy alternatives with no impact on the real environment.

Visualisations can be used as a basis for discussion and debate within the community, having significant implications for the development of effective land-use policy.

6. ACKNOWLEDGMENTS

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