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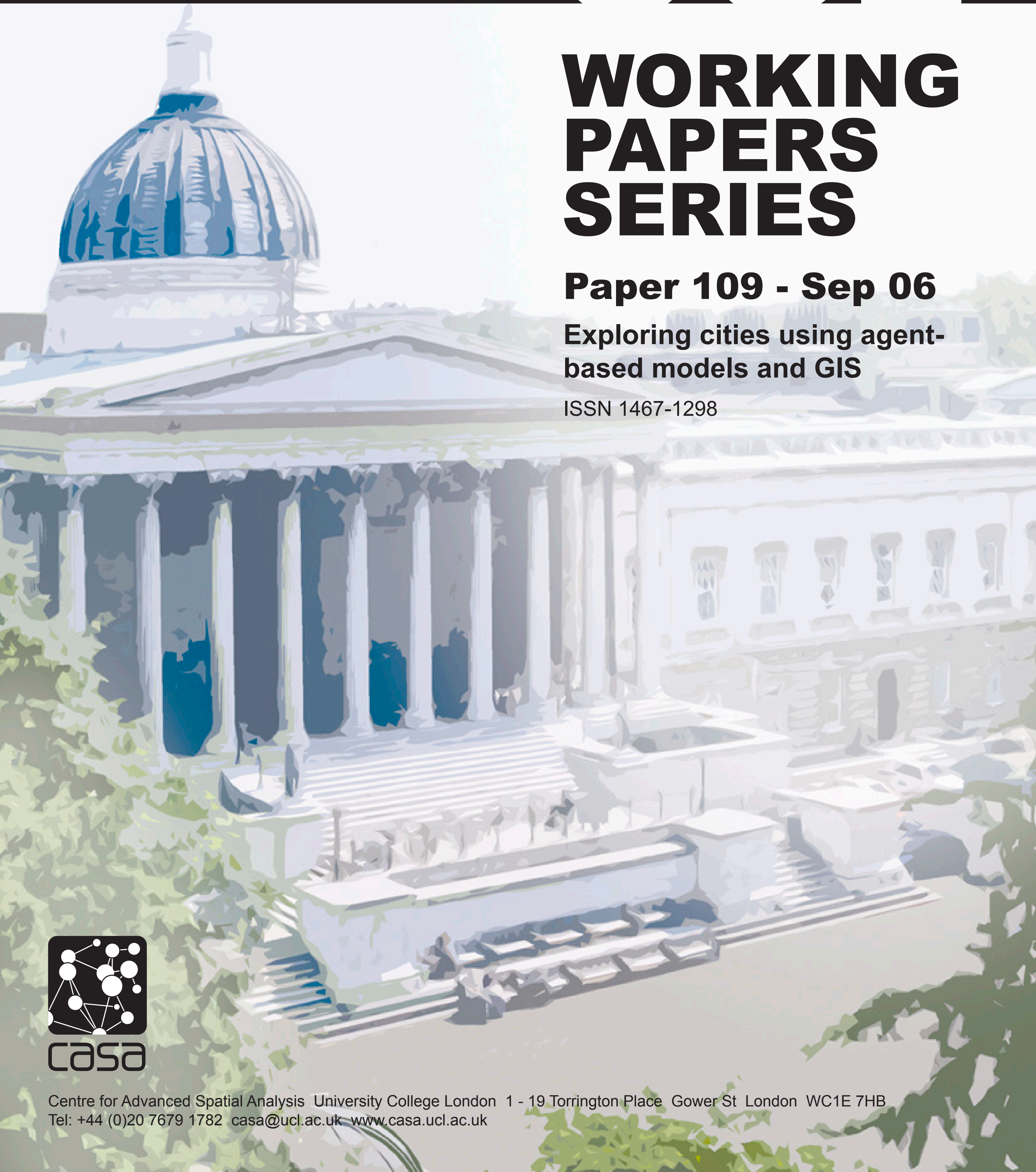

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Exploring cities using agent-based models and GIS

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EXPLORING CITIES USING AGENT-BASED MODELS AND GIS[*]

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ABSTRACT

Cities are faced with many problems such as urban sprawl, congestion, and segregation. They are also constantly changing. Computer modelling is becoming an increasingly important tool when examining how cities operate. Agent based models (ABM) allow for the testing of different hypotheses and theories for urban change, thus leading to a greater understanding of how cities work. This paper presents how ABMs can be developed by their integration with Geographical Information System (GIS). To highlight this, a generic ABM is presented. This is then applied to two model applications: a segregation model and a location model. Both models highlight how different theories can be incorporated into the generic model and demonstrate the importance of space in the modelling process.

Keywords: Agent Based Models, Repast, GIS, Segregation, Bid Rent.

INTRODUCTION

Cities are complex systems, with many dynamically changing parameters and large numbers of discrete actors. The heterogeneous nature of cities, make it difficult to generalize localized problems from that of city-wide problems. To understand cities' problems such as sprawl, congestion and segregation, we need to adapt a bottom-up approach to urban systems, to research the reasoning on which individual decisions are made. ABMs allow us to simulate the individual actions of diverse agents, measuring the resulting system behaviour and outcomes over time; therefore providing a good test bed for developing models of cities. As cities are highly dynamic, both in space and time and secondly, as cities operate on a cross scale basis, propagating through urban systems from interactions between individuals in space to regional scale geographies. For example, it is easier to conceptualize, and model how individual vehicles move around on a road network, where each car follows a simple set of rules. For instance if there's a car close ahead, it slows down, if there's no car ahead, it speeds up and how this can lead to traffic jams without any obvious incident. Rather than producing a series equations that govern the dynamics of vehicles densities. Nonetheless, because vehicle density results from the behaviour of individual vehicles interacting, the agent-based approach will also enable the user to study the aggregate properties of the system.

Najlis and North (2004) discuss that there is a growing interest in the integration of GIS and agent-based modelling systems (Brown *et al.*, 2005; Parker, 2004; Torrens

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[*] This is a modified version of a paper previously presented at the Agent 2006 Conference (http://www.agent2006.anl.gov).

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and Benenson, 2005; to name but a few). Examples of recent applications include pedestrian dynamics, urban growth models and land use models. For agent-based modellers, this integration provides the ability to have agents that are related to actual geographic locations. For GIS users, it provides the ability to model the emergence of phenomena through individual interactions of features on a GIS over time and space (Najlis and North 2004).

In an agent simulation, agents often have some sort of spatial relationship to each other and are situated in an environment, while a GIS can contain multiple layers (e.g. a housing layer, a road network layer, a population layer), whereby each layer is made up of a series of features (e.g. points or polygons, each geo-referenced). This ability to include different features and their attributes of different layers in a GIS, allows for a greater representation of the system of interest when modelling. The combination of layers allows one to model agents of varying types situated within a geographical environment.

The use of vector GIS in ABM, specifically its use of polygons for representation of space is a movement away of from the regular lattice structures used in previous urban models (e.g. Wu 1998). As most features of cities are not regular. The use of GIS allows one to model cities using a variety of different land parcel shapes and sizes. We can deal with objects (such as people or houses) either as fixed or non fixed objects. Both can be coupled through spatial-specific functionality based on objects and their situation in space. Fixed objects are things such as parks which have transition rules and cannot move while non-fixed objects, such as firms or people have transition rules and can move. It is clear that areas do not just change; changes are normally associated with interactions taking place between agents and their environment (O'Sullivan and Torrens, 2000). This interaction allows the underlying urban fabric to change depending on what agents are on top of it. It is clear that fixed and non-fixed objects have close relationships and dependences. Therefore a change in variables of either type will have immediate changes on the other. This change can be detected by geo-referencing the objects and agents simply using x and y coordinates.

This paper presents the development of a conceptual agent based simulation model for the examination of urban issues, focusing on the integration of vector GIS and ABM where space plays a central role in the modelling process. A generic model has been implemented, which allows for global patterns to emerge from the local interactions of individual agents. The generic model was written in Java, an object orientated programming language and extends a number of basic operating classes from the Repast library, an open source agent based modelling environment. Within the model, Repast is primarily used for its display, scheduling, importing GIS vector data (ESRI Shapefiles) along with recording change classes. The program utilizes other Java based GIS libraries especially those from the Java Topology Suite[1] which provide general 2D spatial analysis

[1] Java Topology Suite: http://www.vividsolutions.com/jts/jtshome.htm

functions such as line intersection algorithms and buffering, and OpenMap[2] which provides a simple GIS display with panning and zooming and querying of the GIS layers.

THE GENERIC MODEL

The initial aim was to develop as much as generic functionality into a basic spatial ABM application, which could then be applied to any situation, utilizing the Repast framework specifically the support of vector GIS integration. The basic model can work on many different geographical scales (e.g. boroughs, wards, output areas) without the need for reconfiguration. The generic functions of the model include the reading in of any vector Shapefile (as most data comes in this format, for example: census and geo-demographic data) and then using this as a base for the display of the model and for data input (Figure 1A). The use of polygons to represent space has the added advantages of giving realism to models along with the ability to calculate of topology, for example adjacency of polygons. The model uses attribute data from the Shapefile to create the correct number of agents, whether these are polygons (which are fixed e.g. land parcels) or points (can be fixed or non-fixed e.g. residents located within the urban environment) as described in Najlis and North (2004) along with setting of the initial starting conditions of the model by reading the attributes from the Shapefile, for example land use or the predominant social class of the area. By allowing individual agents to move around and interact in an environment, clusters can emerge across boundaries which would be missed at a higher, more aggregate level data analysis. The ability to use Shapefiles also restricts the agents' movement to within the study area (Figure 1B). Other generic functionality built into the basic model is the interaction between individual agents and between the agents and their environment.

Moving away from the traditional cellular space leads to conceptual problems such as defining neighbourhoods, new searching algorithms, and movement rules. Another problem linked to using vector space is the treatment of physical boundaries (e.g. rivers and motorways) when calculating neighbourhoods. Figure 2 highlights how geographical features (such as a river) can be incorporated into the model when calculating neighbourhoods. Within Figure 2, the black circle represents the agent of interest. This agent wants to know which agents are within a specified distance of itself and in the same geographical area. A buffer is created at this specified distance. However in this case, the buffer crosses the river. Therefore agents on the other side of the river (yellow squares) are not neighbours as there is no way for them to move directly to the agent; however they are within the buffered region (green line). Those agents (red squares) which are on the same side of the river as the agent and are within the agents defined buffer (red line) are classed as neighbours, any agents outside this area would not be classed as a neighbour. This creation of buffers also has the advantage of calculating local statistics such as density of small areas etc.

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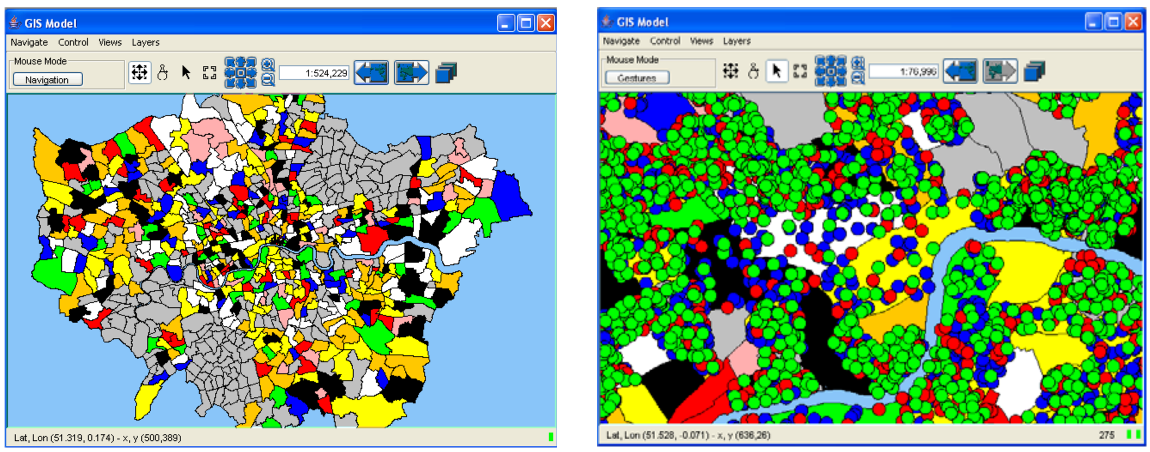
[2] OpenMap: http://openmap.bbn.com/

The generic model uses Repasts inbuilt functions for the recording of change during the simulation run. These include graphing options, screen capture, the creation of movies, and aggregate information in the form of text files, along with the creation of new Shapefiles (Figure 3). The latter allows for spatial analysis after the model simulation has been run, whilst at the same time keeping track of changes in between time steps within the model, for instance changes in population density within the environment as agents move into and out off an area. This recording of change at a higher, aggregate level as well as at the individual agent level, allows one to see how micro change affects higher level viewing. As the models are based on the concept of a tool to 'think with', user interaction is key. User interaction is in the form of parameter settings, the movement of agents via drag and dropping, and the ability to change the agent attributes, all via a graphical user interface which allows for sensitivity testing of model parameters.



A B

Figure 1. The use of polygons. **A**: the underlying polygon layer used to create and set the initial model conditions. **B:** a zoomed in section of A, where agents have been created using data from the underlying polygons attributes.

APPLICATIONS

Using this generic framework, models can be developed rapidly to examine urban issues. Two different model types are presented as 'proofs of concept': a traditional segregation model and a bid rent style model (to analyze firm and residential interaction). Both models are made from a series of layers, composed of fixed and non-fixed objects. All parameters and values used within the models are changeable, opening the model to sensitivity testing making the models exploratory in nature. The models are created with only minor alterations to the basic model structure, highlighting how this approach can be applied to different styles of urban models. Both models highlight how order is possible to emerge from a small number of rules applied locally among many actors which are capable of generating unexpected levels of complexity in aggregate forms.

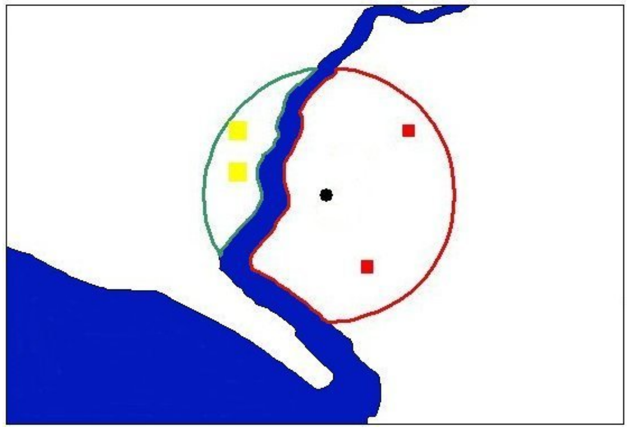


Figure 2. Defining Neighbourhoods with the inclusion of geographical features

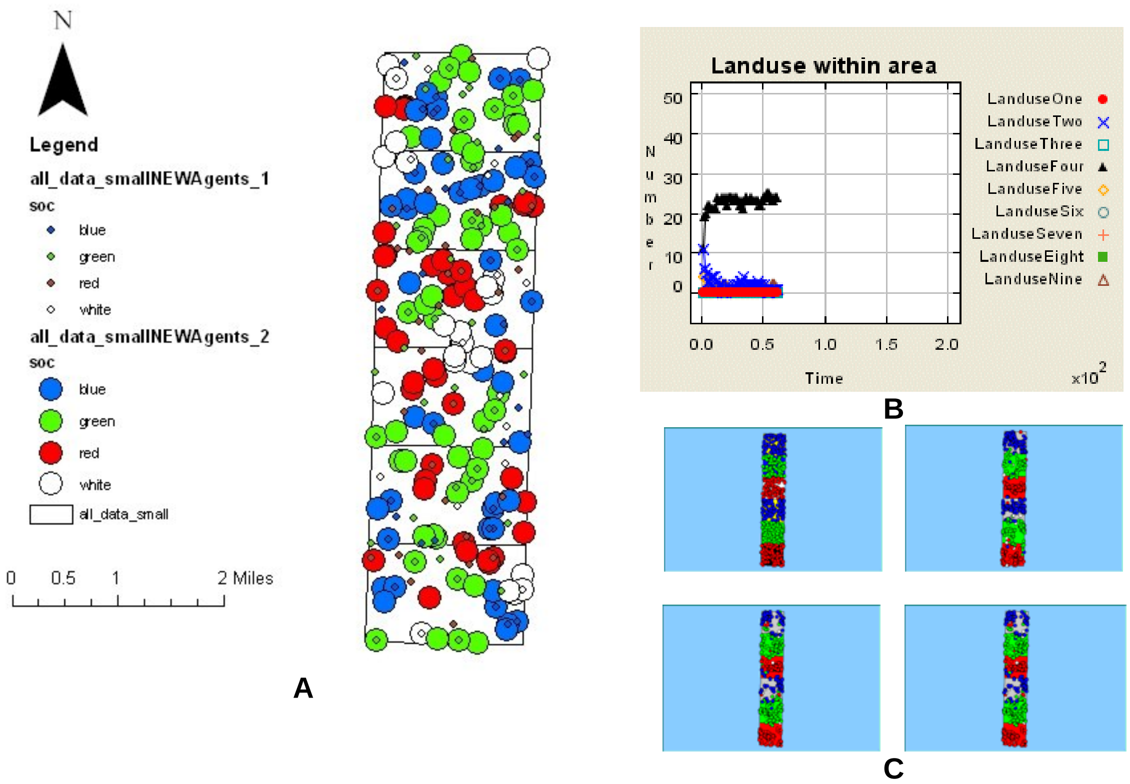


Figure 3. Examples of the different types of outputs from the model. **A:** point Shapefiles of locations of agents in two different time steps (step 2 are the larger circles), **B:** a graph showing land use change during a model run, **C:** a series of screen captures during a model run.

The Segregation Model

There are many different types of segregation, e.g. sex, age, income, language, colour, tastes etc. Although the type of segregation may not be clear or be seen at the individual level, it can lead to surprising and unexpected results once modelled. Some segregation is organized, some is economically determined, or results from specialized communication systems, or the interplay of individual choices that discriminate (e.g. choosing to live in certain places). Schelling believed “that the interplay of individual choices, where unorganized segregation is concerned, is a complex system with collective results that bear no close relation to individual intent” (Schelling, 1969, p488).

Schelling (1969) presented a model on the emergence of segregation where he showed that with mild preferences to locate amongst like demographic or economic activity groups, strict segregation would emerge unknowingly. This segregation is all too clear when one walks around the urban area, there are clusters of economic groups and residential groups based on ethnicity or social class. Batty *et al.*, (2004) write that it is hard to find clear examples of segregation process taking place, because it only becomes noticeable when it is clearly underway, and by then a detailed chronology becomes impossible to reconstruct. Thus segregation is an important issue especially when related to urban growth which can be studied through simulation modelling.

To highlight this idea of segregation based on simple tastes and preferences, a simple segregation model has been created. Individuals are given the same initial starting conditions but different preferences for their types of neighbours. What is clear is that with different percentages of similarity wanted, different patterns will emerge within the model run. However these patterns change as time passes, as the agents move to find areas in which their preferences are satisfied, thus changing the composition of the neighbourhood and the overall appearance of the system. Unlike traditional segregation models, space is not restricted to discrete homogenous cells, more than one agent is allowed per area, and more intelligent movement and searching mechanisms are included (e.g. agents don’t just move to random locations or the nearest empty cell). The incorporation of geographical features (such as rivers) within the model also affects the pattern of segregation that emerges. By altering the preferences within the model e.g. incorporating a density function into the model, can stop the agents from clustering all in one area. The segregation model is a good example of local searching based on small scale neighbourhoods.

The Bid Rent Style Model

The aim of this model application is to study human and firm behaviour at the micro level in a spatial and dynamic context. Micro and macro interaction are linked together, as it is argued that responses to macro policy should be based on the individual (or groups of individuals) whose actions can lead to order at a higher level without structures being imposed from the outside.

The model is based on the ideas of Alonso’s (1964) urban land market theory, which aimed at describing the optimum residential location pattern where land use organization within a city is based on the trade off between many factors (e.g. travel cost, rent and space required). The model presented extends the traditional model to incorporate issues such as time, therefore allowing the system to adapt and evolve to changes in the environment, for example infrastructure investment or population growth. The model also moves away from some of the restrictive assumptions purposed by Alonso, such as a centralized employment. Within the model there are two main groups of agents, the residents and the firms. These are further broken down into subgroups with different incomes and preferences for locations and space. Both of these groups of agents occupy a space and have global searching capabilities. This space contains information on the urban environment such as accessibility, social characteristics of the land and land use which is read directly from the Shapefile.

The ABM approach means households are not treated in the same manner, since each household will have different tastes and preferences, for example for space. The model explores issues such as the exclusion of individuals, and is based on plausible economic decision rules, while at the same time incorporating ideas of distance and price. Locations are determined by a process of bidding (competing) between firms and firms, residents and residents, and firms and residents which introduce many feedback loops into the system along with evolution over time. The model also allows for macro policy to be introduced (e.g. infrastructure investment causes an area to become more accessible). Interactions between individual agents show how local interactions can result in macro patterns emerging.

CONCLUSION

The paper has presented how a simple conceptual model integrating ABM with GIS functionality can be developed and applied to different types of theoretical urban models, where space plays a central role. Changes within the model can be exported in a number of different formats giving the model extra spatial analysis functionality. Two types of model applications where presented as simple ‘proofs of concept’ to highlight how ideas and theories can be easily incorporated into the basic model structure that has been developed. Both models are used to represent dynamic processes of change within the urban environment at different geographical scales. Based on individual interactions we show how emergent structures develop, based on a small number of rules applied locally among many actors.

Currently these models have only been applied to abstract systems, which were designed to test how space affects the simulation outcome. Further investigation will apply the models to real world situations and to study these issues in greater detail at the same time testing different scenarios, such as the effects of different infrastructure investment plans in the bid rent style model. The use of GIS vector data removes some of the restrictive assumptions imposed by cellular automata style models (such as one agent per cell, space being arranged on a regular lattice or neighbourhoods being composed of blocks of cells), whilst giving access to basic data for setting initial model conditions and parameters.

The integration of ABM and GIS gives modellers the ability to link agents to actual geographic locations. For GIS users, this provides an accessible way to model the emergence of phenomena through individual interactions of features on or related to real geographies over time and space. Combined, this can lead to a greater understanding of how cities work and function.

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