ABLOoM: Agent-Based Modelling of Location Behaviour

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Abstract: Complex spatial land use patterns continue to develop around us, accounting for a major source of environmental degradation. Sound environmental management requires an understanding of the mechanisms that are at the basis of land use changes and the formation of land use patterns This paper presents an Agent-based LOcation Model (ABLOoM) that simulates the location decisions of two main types of agents, namely *households* and *firms*. The model contains multiple interactions that are crucial in understanding land use changes, such as interactions of agents with other agents, of agents with their environment and of agents with emerged patterns. ABLOoM allows us to study human behaviour at the microlevel in a spatial context. The models, which include economic theory, aspects of complexity theory and decision rules, show that it is possible to generate macrolevel land use patterns from microlevel spatial decision rules.

***Keywords*:** Land use; Spatial patterns; Location behaviour; Agent-based modelling

1. INTRODUCTION

Why do economic activities cluster? Why do some activities agglomerate into urban environments and why do others show sprawl characteristics? These land use change issues are of importance in environmental management. Socio-economic drivers are considered the most important drivers of land use change. Drivers such as population changes, economic changes and cultural, institutional and political changes constitute a fundamental part of the land use system, but alone are insufficient to explain the land use patterns that we see around us. The ultimate effect of the drivers depends on the decisions that are made by individuals on a microlevel.

The land use system can be considered a highly dynamic, complex adaptive system and it should be studied accordingly. Regional economics and geography provide theories to deal with location patterns and location behaviour, but traditional location theories [e.g. based on Alonso, 1960] are not suited to represent the complex land use system [Otter, 2000]. This is mainly due to the inadequate representation of human decision making which fails to capture that humans have the possibility to adapt to their situation, interact with others and can anticipate to threats or potential changes.

Agent-based modelling is a method to deal with the complexity of land use changes, and especially with microlevel spatial behaviour. Agent-based modelling eliminates the drawbacks of 'traditional' land use theory and modelling, in that it is able to adequately incorporate human behaviour and space. Agents interact with other agents and/or with their environment, according to their behavioural rules. It is a bottom-up simulation approach in which the micro mechanisms of human activity generate macroscopic structures [Epstein and Axtell, 1996]. Recent examples of the modelling of agent behaviour in a geographical context are given in [Bousquet et al. 2001] and [Weisbuch, 2000]. This paper focuses on the emergence of two distinct land use patterns, namely clusters and sprawl.

2. ABLOOM: AGENT-BASED LOCATION MODEL

2.1 Introduction to ABLOoM

ABLOoM is an Agent Based LOcation Model which simulates the location decisions of two main types of agents, namely *households* and *firms* [Otter, 2000]. The model explores microlevel land use decisions that drive macrolevel pattern formation and contains the multiple interactions that are crucial in understanding land use changes. These include interactions of agents with other agents, of agents with their environment and of agents with emerged patterns. The *theoretical* basis of the models is formed by combining three elements. The models are based on:

- spatial human behaviour;
- regional economic concepts [cf. Anas, 1987];
- decision rules [cf. Simon, 1992; Epstein and Axtell, 1996].

2.2 Grid

The grid (or lattice) includes 101*101 cells. On the screen the grid appears to be a square grid with fixed boundaries, but it is actually a torus. The grid is composed of many layers of different types of data, but only one layer is represented. The layers can be 'read' at any time by the agents, they can withdraw values from the cells with which they interact and they can also restore values in the grid.

One of the layers in the model is the initial *'land use'* layer, which consists of three types of environmental attributes, namely 'land', 'natural area' and 'sea'. These attributes are fixed and the initial grid is considered empty implying that no agents have located in it. Agents are only allowed to locate in empty cells that are labelled 'land'. While agents can not locate in 'natural area' or 'sea', they can be attracted to these environmental features depending on their decision rules.

A second type of layer is the *'attraction'* layer. The concept of attraction is introduced to simulate agglomeration phenomena. The rationale behind agglomerations is that some agents, whether households or firms, benefit from being close to each other. Firms are attracted to each other for a number of reasons. Similar firms or shops can be attracted by the presence of markets and potential customers, while dissimilar firms can benefit from delivering goods and services to each other. Households can be attracted to each other for a number of reasons, such as social contacts, the quality of the neighbourhood or the presence of schools and shops. These agglomeration effects are translated into an attraction variable. The attraction variable is one of the multiple issues that agents take into account when making location decisions based on a set of rules. The 'attraction' of a location is not fixed; the agents continuously affect it during the simulation. In our model, a different attraction 'layer' is introduced for each type of agent. Depending on the type of agent involved, it has a varying degree of sensitivity to attraction of other types of agents. The attraction of a location is updated in each timestep.

For methodological issues such as the 'starting time' of agents, the way agents are assigned to the grid and the manner is which they search the grid for a location we refer to Otter [2000].

All agents are given a set of rules, which determine their behaviour in every situation. These rules can have a variety of appearances and act on various scales. The different decision rules can be:

- autonomous: The agents start behaving in a certain manner as soon as the agent is activated. This simulates the autonomous behaviour of individuals that is independent of external stimuli.
- time-dependent: The agent's actions are activated only after a specified period of time.
- environment dependent: The agent's behaviour depends on the characteristics of the environment in which it operates.
- based on interaction with other agents: The agent's behaviour is a reaction to the actions of other agents. In the model we include household-household interactions, firm-firm interactions and household-firm interactions.
- based on interaction with macro patterns: The agent's behaviour is a reaction to the land use patterns that have emerged.

2.3 Agents

2.3.1 Preferences of households

Each *household* has its own characteristics that distinguishes it from others. The characteristics of the agents differ from traditional representations of households in a number of ways. In the dominant neoclassical model of studying human behaviour, individuals (and households) are assumed to show optimising *rational* behaviour based on perfect information. In our agent-based models, agents do not display optimising behaviour, but satisficing behaviour [Simon, 1992]. This implies that due to their perception of reality, as well as due to goals, expectations, hopes and beliefs, the agents have preferences for specific locations. The decision rules of each agent are based on these preferences for specific locations. The preferences reflect the characteristics of the households. These characteristics, which can change over time, include household income, age structure, presence of children etc. but also perceptions, myths and meaning. Not all of these characteristics are included explicitly. The characteristics of each household agent are translated into:

- a preference for employment, neighbours, service levels and environment;
- a visibility.

Concerning *employment*, it is assumed that (one member of) every household is employed in any of three employment sectors. We distinguish between the heavy industry (sector 3), manufacturing (sector 1) and the service sector (sector 2). It is also assumed that the income range of the households is determined by the sector in which they are employed. As a simplification agents employed in the heavy industry have low incomes, those in manufacturing have medium incomes and those working in the service sector have high incomes. The income of a household is one of the characteristics that is translated into its preference for locations. In addition to the influence through 'income', we assume that the employment of the agents also directly affects their locational wishes [Van der Veen and Evers, 1983].

The preference for *neighbours* is closely linked to the 'attraction' variable that was introduced earlier. The rationale of a preference for neighbours is based on the fulfilment of basic needs. Being close to others can fulfil 'social' needs such as gaining respect and having a sense of 'belonging' [cf. Maslow, 1954]. The wish to be close to other agents is also linked to the 'neighbourhood' effects that we find in the literature [Clark and Van Lierop, 1986]. We assume that most households wish to be close to other households since they are social creatures that need contact with other people. Yet, for diverse reasons, some households will wish to be away from others. Consequently, in our model agents can have either a low or high preference for neighbours.

For *service levels*, a distinction is made between preferences for basic and high service levels. The concentration of population will promote a level of services [Harvey, 1996]. A small concentration is assumed to lead to basic service levels, for example the presence of school, shops etc. Larger concentrations lead to high service levels, represented by the presence services such as theatres, libraries, hospitals etc. These services are most commonly found in larger cities. In this model service levels are regarded as an emergent property, since they depend on the size of the clusters of agents [see also Christaller, 1933]. We assume that for high service levels a minimum population of agents must be present.

The *environment* preference was included to indicate the 'natural' value of certain zones and to provide the basis for interactions between humans and nature. The preference for environment represents the wish of agents to live in a location with a high environmental quality. It is expressed in the decision rules as the distance to natural areas. In addition, the natural environment can be used as an input source for the production of goods. Certain input-oriented firms are therefore assumed to have a preference to be close to a natural resource.

Apart from the preferences for employment, neighbours, service levels and the environment, the second characteristic of the agents is that they possess a *'visibility'*. The concept of 'visibility' is included to simulate the effects of a bounded rationality. Visibility in our model is represented as a radius, which the agents use to search the locations around them, starting from their initial position. Since the agents use a 'circular' search mechanism a full visibility resembles a circle that encompasses the entire grid. The *'visibility'* variable is included for two reasons. The first is to counteract the economic assumption of perfect information, which cannot be held in reality. The visibility varies from one agent to the next and thus indicates the visible range that agents have for choosing a new location. It represents how far around households and firms are willing to look for a new location. 'Visibility' is also included to reflect the income of a household. When searching for a location high income households can afford to search in a larger area. Not only can they spend more money on acquiring the information they need, they can afford to live further away from their employment and spend more money on commuting.

2.3.2 Preferences of firms

In addition to *household* agents we included *firm* agents in our model. Each *firm* has its own characteristics by which it can be distinguished. In traditional models firms locate where profit are maximal, or where costs are minimised. Yet, other factors, related to the concepts of attraction and repulsion, also play a role in firm location behaviour. In our model each firm agent is equipped with the following characteristics:

- the sector to which it belongs
- a visibility

The firms originate in three sectors, namely the heavy industry, manufacturing and the service sector. The production of goods in each of these sectors is translated into a requirement for inputs. Two types of input requirements are distinguished, i.e. for employment and for natural resources. Depending on the production characteristics, the requirements for employment and natural resources are specified. Each type of firm can have low, medium or high employment requirements and low, medium or high resource requirements. These requirements greatly affect the location choice of firms. Consider, for example, internet companies that are driven primarily by human capital and have no requirement for natural capital.

Table 1 summarises the agent characteristics for households and firms. All agents possess a certain combination of characteristics presented in Table 1.

Table 1. Agent characteristics.

households	preferences	employment in sector	1
			2
			3
		neighbours	low
			high
		services	basic level
			high level
		environment	no
			yes
	visibility		limited
			full
firms	sector	employment in sector	low requirement
			medium requirement
			high requirement
		natural resources	low requirement
			medium requirement
			high requirement
	visibility		limited
			full

In ABLOoM, eight different types of agents are distinguished. These consist of five types of household agents and three types of firm agents. Household1 agents can be considered 'pioneer' agents. They are the first to settle and form the basis for further development. Household2 agents are assumed to be low-income households and Household3 agents are high-income households. Household4 is mainly driven by a high preference for environment and Household5 is mainly driven by a repellence of other agents. Firm1 represents a firm in the manufacturing sector, Firm2 a firm in the service sector and Firm3 a firm in the heavy industry sector.

Based on their characteristics the agents have a set of decision rules which guides their actions and interactions with other agents.

Initial values for the agents in the simulation include the number of agents that are included of each type, the colour by which the agents can be identified on the grid and their starting time interval. The starting time is the time at which the agents turn 'active', thus at which they are included in the model. In ABLOoM, the starting time is picked randomly by each agent from a time interval, which is determined by the modeller. This implies that, rather than all agents of one type having the same starting time, individual agents of the same type are generally activated on different starting times within a certain interval.

For various types of agents multiple time intervals are presented. This is a time-dependent characteristic and simulates that these agents grow older and this is assumed to be accompanied by a change in preferences. Therefore, a second time interval is introduced in which the agents change their behaviour.

2.4 Results of ABLOoM

The land use decisions of the agents in ABLOoM, generate land use patterns such as presented in Figure 1. Different patterns emerge from different simulation runs. Clustering and sprawl patterns have been generated in a variety of models which include different combinations of different types of agents. The models include rules that are either autonomous, time-dependent or based on interaction with other agents or with emerged phenomena. These rules drive the evolution of the system and lead to three land use 'phases' in the model results:

- initial development phase
- growth phase
- stable or dynamic equilibrium phase

The initial development phase is the phase in which a relatively small number of agents has found a location. In the growth phase a larger number of agents has found a location and this development influences the location decisions of the agents that are still searching. In the growth phase of this particular simulation a cluster is being formed by household and firm agents. These agents are drawn towards each other for different reasons depending on their decision rules. In the last phase all agents have settled on the grid (see Figure 1). This does not automatically imply that a static equilibrium has been created, in the sense that all agents will stay at their chosen location after this time. Agents can still move around depending on their decision rules.

Each dot in Figure 1 depicts a household or firm agent. Each type of agent is represented by a different colour. Figure 1 shows the result of a simulation in which all agents are assumed to have full visibility. A land use pattern has emerged with one large cluster of agents and a number of agents that appear to be spread across the grid. This cluster and sprawl pattern is a result of the agents' actions and interactions based on their decision rules.

Figure 2 shows a graph for the macro level features, namely the number of agents that have found a location over time.

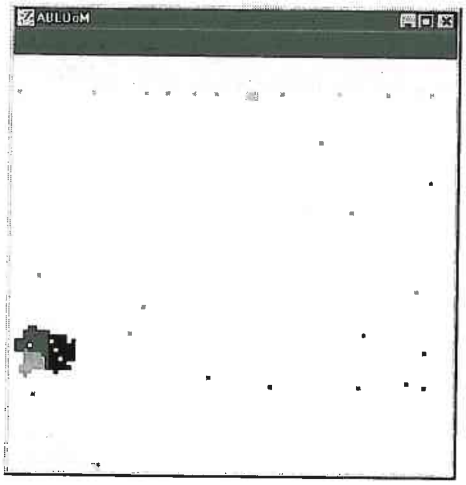

Figure 1. Results of ABLOoM (full visibility).

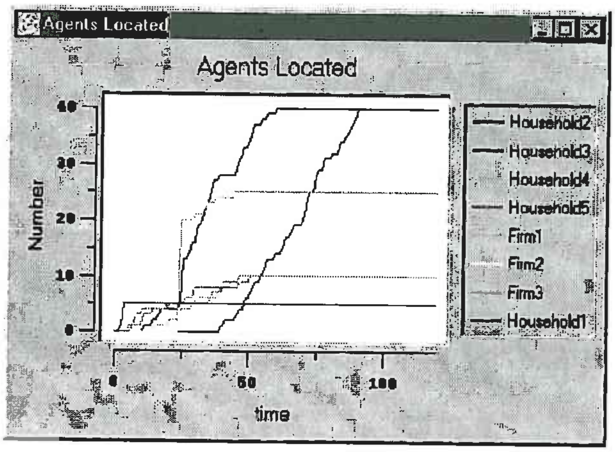

Figure 2. Macrolevel features of ABLOoM (full visibility).

The results from this simulation and others [Otter, 2000] show that it is possible to generate macrolevel land use patterns from microlevel spatial decision rules. The clustering and dispersion patterns that have emerged show a good resemblance with real-world patterns. The conclusion is that agent-based models are a good tool to approach the simulation modelling of microlevel processes.

3. ACKNOWLEDGEMENT

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