Irregular vector-agent based simulation for land-use modelling

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ABSTRACT

Urban structures exhibit complex patterns made of heterogeneous and irregular objects. Few works in the computational urban modelling literature have considered and examined the real geometric boundary of the city's objects. However, most of these works are driven by Cellular Automata (CA) as a spatial modelling vehicle. This model has had success, but also has its limitations regarding the study of urban dynamics in computer simulation. Extensive modification of CA or use of a different modelling paradigm should be considered. We argue here that, representational realism must be achieved in urban complexity. This paper is an attempt to fill this gap to address the rigid structure of CA: we present a novel technique called the "*vector-agent based simulation*", which uses discrete irregular objects as an autonomous spatial entity beneath an agent modelling structure. Through computer simulation, this new technique has been applied to von Thunen's theory of agricultural land use as a hypothetical environment for model verification. The findings demonstrate that our proposal can be a new paradigm for urban simulation

1.0 INTRODUCTION

Considering city form, growth and differentiation as complex phenomena for spatial simulation, Cellular Automata (CA) has received great attention and is one of the most established models in the literature (Batty, 1997; Batty and Xie, 1994, 1997; Batty *et al.*, 1999; Couclelis, 1985). CA models have been employed in the exploration of a diverse range of urban phenomena, from regional scale urbanisation (White and Engelen, 2000) to land-use dynamics (Batty *et al.*, 1999), polycentricity (Wu, 1998), socio-spatial dynamics (Benenson *et al.*, 2002), segregation (O'Sullivan *et al.*, 2003), and gentrification (O'Sullivan, 2000, 2001).

CA are an abstraction, simplified representations of phenomena, that operate in the physical world as aids in the understanding of how the dynamics of those systems function. The character of CA as applied to the study of urban phenomena departs significantly from the strict mathematical formalism by Ulam, von Neumann, Conway, and Wolfram (Wolfram, 2002). At the most abstract level, a cellular automaton is an array or lattice of regular spaces or cells. At any time in a simulation run, a particular cell is one of a finite number of allowed states. The state will change according to the states of neighbouring cells in the lattice, subject to a uniformly applied set of transition rules. Cells alter their states iteratively and synchronously through the repeated application of these rules. A CA is thus composed of five elements: a lattice (square-grid), a set of allowed states, neighbourhood defined by immediate neighbouring cells, transition rules, and time or the temporal aspect. These simple elements of CA, their relative ease with which model results can be visualised, their flexibility and dynamic approach, and the link they provide with the geographic information system and remotely sensed data, have made CA one of the favoured techniques for simulating urban phenomena.

However, long debates have been articulated about urban modelling with the strict formalism of CA (Torrens and O'Sullivan, 2000). They pointed out;

> *"….. the basic CA formalism is not well suited to urban applications; the framework is too simplified and constrained to represent real cities. Indeed, radical modification is necessary before CA can approximate even a crude representation of an urban system. This often necessitates the introduction of additional components to add functionality to the basic CA framework."* (pp. 163-164)

These restrictions have resulted in a great number of additions to the strict CA formalism in terms of spatial complexity and urban simulation research.

The dimension and structure of CA lattices have been modified to cope with the regularity of square-cells. While most features of cities are not regular, the assumption of regularity is questionable and doubtful for urban application. A limited number of researchers paid attention to and changed the lattice structure in CA model, by introducing the irregular cellular automata using a Voronoi diagram (Flache and Hegselmann, 2001; Shi and Pang, 2000).

In terms of the simplest CA-states, a cell has only two binary values; for example (0) for death or (1) for life in the case of Conway's Game of Life (Wolfram, 2002), or non-change and successful development in the case of a cellular urban model (Batty and Xie, 1994). This raises the problem of how to differentiate or rank the cell state in simulating some urban phenomena such as population growth rate or land use suitability. The concept of the grey-state of a cell has been introduced to represent the level of development of a cell and overcome the unit problem in standard CA simulation (Li and Yeh, 2001; Yeh and Li, 2001, 2002).

The neighbourhood of a cell in the CA formalism consists of the individual cell itself as well as a set of adjacent cells. There are two popular neighbourhood configurations: the von Neumann neighbourhood of the four directly adjacent cells, and the Moore neighbourhood consisting of the eight cells that form a square around the cell that is being processed. This regularity in neighbourhood configuration contradicts any distance function, which is a part of the dynamic process in the city (Torrens, 2000). Recent development in urban cellular models have moved away from this simple approach to neighbourhood configuration using Delaunay triangulation (Semboloni, 2000), planar graph (O'Sullivan, 2000, 2001), and geo-algebra (Takeyama and Couclelis, 1997). The structure of the standard CA has therefore been generalised to accept arbitrary, spatially variant neighbourhoods, making the CA formalism more dynamic and flexible.

Transition rules for urban models have also been modified, opening up to exogenous links and making the change via a feedback mechanism as a cellular automata evolves. Utilising methods such as genetic algorithms (Colonna *et al.*, 1998), spatial optimisation (Goldstein, 2003), and neural networks (Li and Yeh, 2001), the transition function is allowed to evaluate new possible rules through evolutionary and learning mechanisms.

The treatment of time in CA has not escaped the attention of researchers exploring urban simulation as a temporal domain. In strict CA, cell state is updated synchronously as transition rules are applied simultaneously at every location. As the city has multiform temporal dimension, sequential update is clearly uncertain or inconvenient for simulating urban phenomena. Unfortunately, few studies have explored the synchronous *vs.* asynchronous CA update in an urban context. White and Engelen (2000) have modified the cell update so that it is partly sequential. In another example, Portugali (2000) has experimented with the asynchronous cell-state update in accordance with the actions of agents in cellular space.

This large number of modifications to the basic CA framework has moved the research community towards an integrated CA with multi agent system (MAS). In the urban environment, the agents imitate the mobile entities; e.g. people, vehicles, …etc. (Haklay *et al.*, 2001), or households and social factors (Barros, 2003; Benenson *et al.*, 2002; Portugali, 2000). Such cooperation has offered CA more dynamics and flexibilities, which mimic the agent system behaviour.

Obvious questions arising from this discussion are, "*What consequences are there for these extensive modifications in the phenomena being modelled?*", "*Do these modifications lead urban simulation towards the needed degree of realism?*", and "*Is CA an only tool solution for urban simulation?*".

It should be made clear that these extensive modifications may move the attention of model developers away from exploring the idea behind how the phenomena is being processed and how the systems function, and lead to a more chaotic model structure. Moreover, urban simulations are an abstraction and simplification of real world objects that may be used as laboratories for exploring ideas about how cities work and change over time. The CA, even modified-CA, cannot therefore truly model the real world entities. In an urban context, we are concerned with unpredictable and irregular objects. In a simulation domain, objects must therefore be allowed to evolve and interact with each other in an irregular fashion, taking into account the object geometry. This cannot be conceived using CA, especially with its rigid square-grid space, even with Voronoi space. The regular partition of space as a conceptual basis should be substituted by another approach. The need for a more flexible, and dynamic spatial model with no supplements or modifications, could provide the answer for the last question.

Therefore, this paper intends to propose such an alternative and a novel approach: irregular vector agents by means of autonomous discrete objects. The model is based on an irregular vector data structure and influenced by agent-based modelling. The main aim is to simulate some geographic (in this case urban phenomena) and represent individual objects entities by their real geometric boundaries. Considering the proposed model structure, the main hypotheses are:

> - *The model has an advantage of being more realistic, flexible for representing the real world features, such as buildings, roads…. etc, not generalised square grid-cells.*
> - *The model maintains the topological relationships that are subject to change during the object life. Therefore, the neighbourhood relations have no restrictions as in CA.*
> - *The model has advantages of being constructed under the object oriented paradigm and agent modelling. These can influence in the system hierarchy and behaviour that is closer to real world entities.*
> - *The model maintains the top-down and bottom-up approach powered by the agents' hierarchy, which is central in spatial or more specifically urban simulation. This cannot be achieved using strict CA, which is inhabited by local individualistic actions that lead to global patterns.*

On the other hand, calibrating the proposed computational paradigm with real world phenomena is another concern in this paper. Classical urban theories have been chosen to examine and establish the spatial model hypotheses. In addition, research in this area has potential to offer new insights into the urban model, serving as vehicles for the generation of new ideas, and as a laboratory for hypothetical urban experimentation (Torrens and O'Sullivan, 2000). We argue here that rules and pattern can therefore be explored, which are the key for understanding urban complexity.

In the next section, we outline our hypotheses for constructing the generic model. In section 3 we employ the model strategy for calibrating von Thunen's theory. The theory's assumptions will be discussed in detail and we provide description and experimental results for the irregular vector-agents based simulation in von Thunen's isolated space. Finally, we conclude the advantages of utilising the model as a new approach for urban simulation.

2.0 STRATEGY AND HYPOTHETICAL SCHEME FOR THE GENERIC MODEL

This section addresses and demonstrates the model components' structure. For justifying our hypotheses, the model will be strengthened and examined using the basic five elements of CA: *space*, *neighbourhood*, *transition rules*, *state*, and *time*. Adding to that, the *agent* is introduced as a most important component, which controls and drives the model into an optimal degree of dynamism and realism in the simulation domain.

Formally, we assume that the model can be represented as a set (space) **S**, which has a finite number of subsets **s** **(**discrete objects**)**.

$$\mathbf{S = \{s_1, s_2, s_3, \ldots\ldots, s_n\}}$$

Each subset consists of elements $\mathbf{e_i}$, which is not a member of any other subset **s**.

$$\forall\ \mathbf{s_i = \{\ldots.., e_i, \ldots.. \mid e_i \in s_i \mid \forall\ e_i \notin s_2, s_3, \ldots., s_n \mid s_i \subseteq S\ \}}$$

This in general formulates a relationship scheme between an object class (*superclass*) and one or more refined versions of it (*subclass*).

2.1 Agent

The concept of the agent was initially developed from distributed artificial intelligence (DAI), a branch of Artificial Intelligence that deals with the solution of complexity by networks of autonomous, cooperating computational processes called agents (Jiang and Gimblett, 2002; Rodrigues *et al.*, 1998). There is no common agreement for defining the term agent, and researchers over time have proposed various definitions for the term, and are still doing so (Russell and Norvig, 1995; Xu, 2003). However the most common definition is that; "an agent is a computational entity such as a software program that can be viewed as perceiving and acting upon its environment and that is autonomous in that its behaviour at least partially depends on its own experience" (Weiss, 1999, pp. 15).

There are similarities between the object-oriented (OO) and agent-oriented paradigms, where the agents can be considered as active objects (Xu, 2003). In this paper, we pursue this direction and apply OO to an active object based on a determined set of goals for controlling its response and action, and will be referred to as an autonomous object. Moreover, as the model is driven by agent strategy, higher level of agents has goals functioning upon that control the simulation domain in micro-macro level.

2.2 Space and Domain

From a vector-agent standpoint, we consider the world as a serious of entities located in space. Entities are usually an abstraction of the real world. An autonomous active object or agent is a digital representation of all part of an entity.

A general tool in the context of specifying the spatial properties of a set of objects is the partitioning of space into polygons. Various metrics are possible: a Voronoi approach is one such. In this model, regions are associated with objects (usually points as Voronoi generators) according to which is nearest, resulting in a spatial partition that produces the polygonal structures. Extension and adoption of the basic Voronoi concept can be based on different metric systems; e.g. weighted Voronoi diagram, higher order Voronoi diagram, … etc., but this is beyond the scope of this paper (see Okabe *et al.*, 1992 for more details). Although Voronoi is a mathematical formalism, this can form a basis for constructing the model space. However, any change that occurs in one element can influence in changing the geometric construction for some other elements. Therefore, the autonomy of sub-elements in a Voronoi diagram is questionable.

As mentioned, the primary purpose of this model is to present real object entities considering their real geometric boundaries with respect to its size in space. The object (i.e. polygon) must have freedom to initiate, evolve, and destroy itself in the simulation domain. Thus, this cannot be achieved by using the mathematical assumptions of Voronoi region. Moving towards a more flexible approach is needed.

Batty and Longley (1994) examined the technique of random midpoint displacement in a geometric shape for verifying the concentric city pattern based on fractal simulation. Despite the fractal dimension as an aim for their study, we follow and adopt this technique in a more flexible and dynamic approach for generating irregular tessellating objects. Each line in the object in question is treated as an initiator. The midpoint and perpendicular displacement parameters altered as functions of randomness reflecting the object's evolving direction as the phenomena parameters are being modelled. Thus, generating an irregular shape in each initial step or according to system demands is guaranteed (figure 2.1).

Furthermore, the unitary spatial entities with their respective boundaries can be considered as objects. Each of which stores the location information using the coordinate (*x, y*) system as well as area size. As a result, space can be populated by individuals assembling the real-world entities. This concept also enables substitution of objects in different types while leaving the rest of the system unchanged. One of the merits of this approach, is that the system can end up with unconnected clusters, each of which has its own entity.

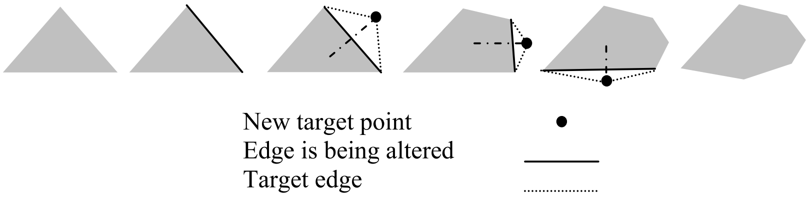


Figure 2.1: How shape evolves in simulation domain

2.3 Adjacency and Neighbourhood

The concept of neighbourhood is entirely based on adjacent formulation. For instance, the neighbourhood of a particular spatial entity can be defined as the set of all other entities adjacent to the entity is being observed. Alternatively, the neighbourhood of an entity may be defined, not with respect to sets of adjacent entities, but as a region of space (i.e. spatial proximity) associated with that entity. This can be defined by a certain distance from the object under question. In this paper, the concept of neighbourhood distance will be employed, where the model is calibrated with one of the land use allocation theory that distance is a deriving rule.

The model may also be examined from a number of perspectives, using a range of already developed metrics (Delaunay triangulation, and planar graph). Briefly, Delaunay triangulation is simply formed as the dual of the Voronoi diagram. Using Voronoi generators, Delaunay triangulation partitions Voronoi polygons into triangles so that each circumcircle of constituent triangle does not include any other triangulation point within it (Okabe *et al.*, 1992). Whereas a graph in general, is an abstracted model of spatial relationships that represents connectedness between elements of the space. The graph consists of a finite non-empty set of vertices (nodes) with a set of distinct unordered pairs of distinct nodes, called edges (Worboys, 1995). The planar graph is a graph that can be embedded in the plane so that no two edges intersect, except at the vertex they are both incident.

Although, the neighbourhood relation is subject to change with respect to object life or position in space, this approach would guarantee the neighbourhood concept is no longer a symmetrical relationship. Whereas, in basic two-dimensional CA, there are two symmetric and fixed popular neighbourhood configurations: the von Neumann neighbourhood and the Moore neighbourhood.

2.4 Transition Rules

Transition rules are the real driving force behind any spatial model. Generally, transition functions serve as the algorithms that code the real –world behaviour into the artificial spatial model. Transition rules are generally formulated as IF, THEN, and ELSE statements that represent the logic of process which is being modelled, and end up with global system pattern.

In CA, the transition rules specify the behaviour of cells between time-step evolutions, deciding the future conditions of cells based on a set of fixed rules that are evaluated from the CA neighbourhood concept.

Our model shares same definition of transition rules with CA. However, it also employs other approaches for observing and functioning such rules. Since our model is built upon an agent system, there are no neighbourhood restrictions for processing transition rules in each object. The autonomy of objects allows specifying whether it can change its state or not, deform or remain the current shape, or remove itself from space. The object utilises its inner rules against the global rules for the phenomena is being modelled. This naturally leads to the concept of a hierarchy of agent classes (*Micro*, *Meso* agents), with higher-level agents (*Macro* agents) controlling and balancing whole system as mentioned before. Such a hierarchy can be described as follows:

Individual entity objects; all objects have same entity will have same desire and goals forced by same rules. They in turn belong to one type of agent, which can be specified as a micro-agent.

Geometric agent; governs all process of the tessellation algorithms, and regards to meso-agent in a hierarchy level. This agent controls size, shape, and position for each individual feature in the micro-agent group. It is also able to consider the interrelations between individual entity objects and long-term system pattern.

System or Macro agents; they inhabit all system rules for the underlying phenomena or the task being processed by the spatial model. They are able to modify the pattern generated by the model at a general level. These agents consist of a set of specific parameters, the probability of development and state change threshold for each entity, and controlling algorithms that influence and are being practiced in previous lower level agents.

2.5 State

Object changes are based on the adaptation of an entity to its environment by the process of differentiation and increasing shape structure complexity. Generally autonomous objects focus on their interactive behaviour in a system environment.

The model attempts to introduce a greater degree of sophistication into an object-state by permitting objects to adopt several parameters simultaneously (e.g. current object's area size with the maximum area the object is allowed to occupy, the current entity of the object and system demand of that entity in macro scale). In this sense, heterogeneous variables can be introduced and the implications of their interaction examined. Rules are constructed so that each variable is updated separately according to internal and external relations with other objects. In other words, object becomes an open and flexible entity, able to be influenced by another object's state with similar or dissimilar entities. This may be a significant advantage, since various parameters can be combined and derived by rules that affect system outcomes.

Here, it should be made clear that the strength of this model is the facilitation of the bottom-up and top-down dynamic approaches by acting on a central entity state, and observing the long-term system pattern respectively. This is not central to the notion of CA, where the future state of a cell depends on its current state and the states of its immediate neighbours.

2.6 Time

In the lifespan of an entity, changes occur describing the evolution of its inner existence, or a mutation of its location in space. The model implements two time modes: *synchronous* and *asynchronous*.

Synchronous; in this mode, all objects are assumed to change simultaneously. Conflicts however arise when agents compete over limited resources. For example, two objects (assuming that they have different entity) are neighbour sharing same unoccupied space, each of which is trying to extend or occupy this adjacent location. Resolution of these conflicts depends on how the model behaves in *asynchronous* mode.

Asynchronous, in this mode, the model is responsible for defining an order of object actions. This may be according to random sequence, or model demands priority as a decision from highest level of system agents. Conflicts between objects are thereby resolved.

Processing the model within both modes provides a highly dynamical approach through the time, which is not central in strict CA, where the cell is updated synchronously in each time step.

3.0 MODEL CALIBRATION AND EXPERMINTAL RESULT

Our objective is to reproduce von Thunen's model of agricultural land use using irregular vector agents, as illustrated above. This computational paradigm can thus be sifted with further development into an urban simulation context. Calibrating classical urban theories for testing spatial models or proving some hypotheses is not new in literature. Schelling's Dynamic model of segregation (Schelling, 1969) has been implemented for exploration of the important role of information in residential location decision-making (O'Sullivan *et al.*, 2003) using RePast agents' library (Collier, 2003). Schelling's model has also been implemented on fixed real world census data (US counties) in RePast as an extension model. This model is considered as the first amongst agent builder toolkits to tackle vector data. However O'Sullivan and his colleagues carried out their work using a cell-based agent technique. Where von Thunen's theory has attracted other researchers as a theory-based foundation for verifying the agent modelling for land use simulation (Sasaki and Box, 2003). In this work, CA and an agent-based model were developed to capture von Thunen's assumptions using the Swarm simulation system. Briefly, Swarm was developed at the Santa Fe Institute in order to provide researchers with a set of standard simulation tools, and is cell-agent based (Minar *et al.*, 1996). In same sense, Turton (2003) investigated the use of intelligent multi agent models for developing von Thunen's theory in his ongoing research using RePast agents library mentioned above.

Our attention now will switch to von Thunen's theory in more detail to tackle and verify our proposed model by extracting the main concept and parameterise elements of the theory as a testing-ground for laboratory simulation.

3.1 The Main Concept of von Thunen's Theory

Johann von Thunen (1826) was the first to develop a basic analytical model of the relationships between market, production, and distance (Rodrigue, 2003). For this purpose he looked upon the agricultural landscape. The relative costs of transporting different agricultural products to the central market determined the agricultural land use around a settlement (market). The most productive activities will thus compete for the closest land, and activities not productive enough will locate further. The model has a set of basic assumptions which reflects agricultural conditions around a city in the early 19th century:

Isolation: There is one isolated market in an isolated state having no interactions (trade) with outside.

Ubiquitous land characteristics: The land surrounding the market is entirely flat and its fertility uniform (i.e. isotropic).

Transportation: It is assumed there are no transport infrastructures such as roads or rivers and the farmers are transporting their production to the market using horses and carts. Transportation costs are dependent on the type of product being transported to the market as well as the distance involved.

The model compares the relationships between production costs, the market price, and the transport cost of an agricultural product, which is expressed as:

$$\mathbf{E = Y/(p-c-rd)}$$

Where **E** is rent per unit of land, **Y** the yield per unit of land, **p** the market price per unit of yield, **c** the average production costs per unit of yield, **r** the transport costs per unit weight per unit distance from the market, and **d** represents the distance from market. von Thunen refined his restrictive assumptions showing the effect of modifying transport cost through the introduction of a navigable river into the system (Wilson, 2000). Figure 3.1 shows von Thunen's theory pattern in both isolated and modification state with transport system.

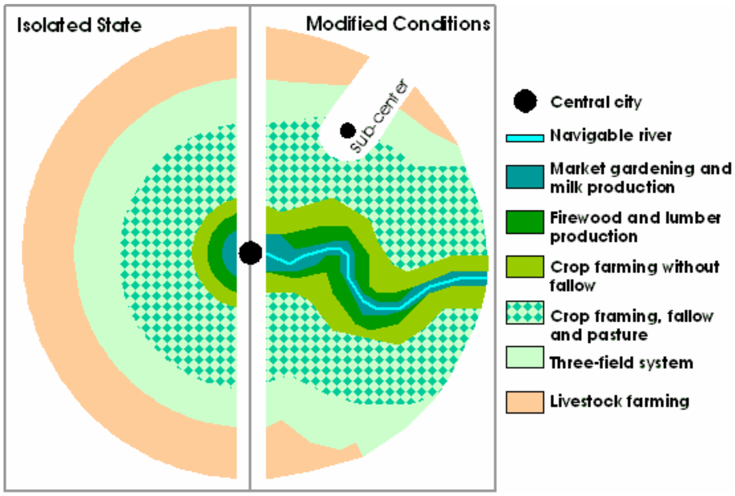


Figure 3.1. von Thunen's theory (source: Rodrigue, 2003)

3.2 Simulation Description

The aim of our simulation model is to clarify the use of irregular vector agents in capturing von Thunen's theory. Most of the parameters have been borrowed from Sasaki and Box (2003) cell-agent simulation. However, our approach is different from that as we try to build the spatial model based on an irregular vector simulation. Therefore, Swarm or RePast cannot be used as a model builder that is cell-based agent.
The model was elaborated in such a way that the behaviour rules are as simple as possible. It is totally based on autonomous vector object environment relationship underlying the process of von Thunen's equation illustrated above. The model was built on a Java platform that expands on our previous strategy for simulating an irregular shape. In this case, each shape is autonomous agent that is made up of rules defining its goal and behaviour in an attempt to reproduce von Thunen's pattern. Each object will represent a farming family in the simulation world.
The simulation consists of the main classes for an interactive user interface, and four classes that inhabit four types of agent. These agents are:

City agent: the market which collects the agricultural products and generates farmer families, and is controlled by an Analysis agent. This agent has the following properties:
- Controls the families who seek to invest money in agriculture.
- Sells different product types that families produce.
- Defines the nearest vacant land outside the market for investors.

Analysis agent: this is the main economic agent, which has the following properties:
- Calculates current production based on the total units harvested in each product.
- Estimates average income of families farming each product and for city-dwellers.
- Generates economic report to City and Farmers agents.

Farmer agent: one farming family occupies each agent. The Farmer-agent has the following properties:
- Farms one production type.
- Defines the target extension for its land based on the irregular shape simulation algorithm that is responsible for allocating the targeted (x, y) position.
- Calculates the rent based on von Thunen's equation for land rent per unit.
- Receives an economic report generated by Analysis-agent for specifying the family income. Based on this report, each family has three choices; continuing practice in same product, shifting into another product, or changing to be a city-dweller.

World agent: an isolated space in which farmers live and practice their agricultural type.

In our simulation, von Thunen's pattern is simplified into four type of products and refereed as product A (intensive agriculture), B (forest resources), C (grain farming), and D (livestock farming). According to von Thunen's generalised assumptions, these different types of agriculture will form in concentric rings around the market, ordered in distance from the city market according to their relative perishable ability and transportation cost to the centre. More specific, any intensive agriculture is the most productive activity (product A), including fruits, vegetable, and dairy, which are more perishable and must be transported immediately to market. Therefore, such product will compete to allocate closest to the market. Whereas, the less relatively important activities (transportation and production-wise), forest, grain, and livestock (products B, C, and D) are more likely to allocate further from the market with increasing distance in that order. Consequently, at the beginning of the simulation, initial values are given to relevant parameters in the modelled world, which are illustrated in table 3.1. As mentioned above these values have been borrowed from the literature (Sasaki & Box, 2003) and adopted to suit our simulation approach. For instance, in our case each family occupies one object (equilateral triangle in its initial state), whereas Sasaki and Box refers to 150 families in each cell. Moreover, the unit area is calculated based on each shape not per cell.

Variables	Value	Description
initCityDweller	104	Initial number of the families
initShapeArea	328	Initial area unit (i.e. initial triangle area)
agriAArea	328-425	Range of areas occupied by product A
agriBArea	426-500	Range of areas occupied by product B
agriCArea	501-550	Range of areas occupied by product C
agriDArea	≥ 551	Range of areas occupied by product D
agriAProduction	1800	Productivity of product A per unit
agriBProduction	2500	Productivity of product B per unit
agriCProduction	900	Productivity of product C per unit
agriDProduction	400	Productivity of product D per unit
agriAPrice	8	Market price of product A
agriBPrice	3	Market price of product B
agriCPrice	5	Market price of product C
agriDPrice	7	Market price of product D
agriACost	3	Cost of product A per unit
agriBCost	0.5	Cost of product B per unit
agriCCost	1	Cost of product C per unit
agriDCost	1.5	Cost of product D per unit
transCost	0.05	Transportation cost per unit distance
transDist	1	Distance unit from the city centre
agriADemand	30	Initial demand for product A
agriBDemand	80	Initial demand for product B
agriCDemand	80	Initial demand for product C
agriDDemand	30	Initial demand for product D
minSatisfaction	-5	Minimum level of satisfaction

Table 3.1. Initial parameters for simulation

3.3 Agents' Behaviour

At every time step, the following actions occur:

- The Analysis agent collects the economic information from the City agent and collates the supply and demand in every agricultural product, and sends the City agent an economic report. The report provides the estimation for a number of Farmer agents whose seek to practice different agricultural types outside the market.
- City agent conducts previous information and initialises a random number of families and allocate the nearest vacant land to conduct their business. This is performed as the following steps:

```
Input: initial equilateral triangle (Farmer agent is being moved from the city), integer f = 0
Output: new Farmer agent outside the market placed in World agent
Step 1. Construct the initial triangle circumcircle
Step 2. Place the circle at the market boundary with predefined-distance from Farmer agent centroid
Step 3. Do until f = 1
            Perform a collision test with existing shapes in World agent included within the distance
            if any shape lies inside the circle
                then move circle one step (incremental x, y of a circle-centroid) counter-clockwise
                Perform collision test.
                          else go to step 2 with incremental distance
                                   else If collision = null
                                   f = 1
Step 4. Place the initial triangle with one step random expand
```

- Farmer agents allocate themselves in the World agent and start to compete in order to maximise productivity by expanding their units using the irregular structure methodology. In addition, each farmer collates his/her income as follows:

1- Collate profitability

farmer(i)Revenue = agri(i)Price * agri(i)Production * agri(i)Area / initShapeArea
farmer(i)Cost = agri(i)Cost + (transCost * transDist)
farmer(i)Rent = agri(i)Production / (agri(i)Price – Farmer(i)Cost)
farmer(i)Income = farmer(i)revenue – farmer(i)Cost – farmer(i)Rent

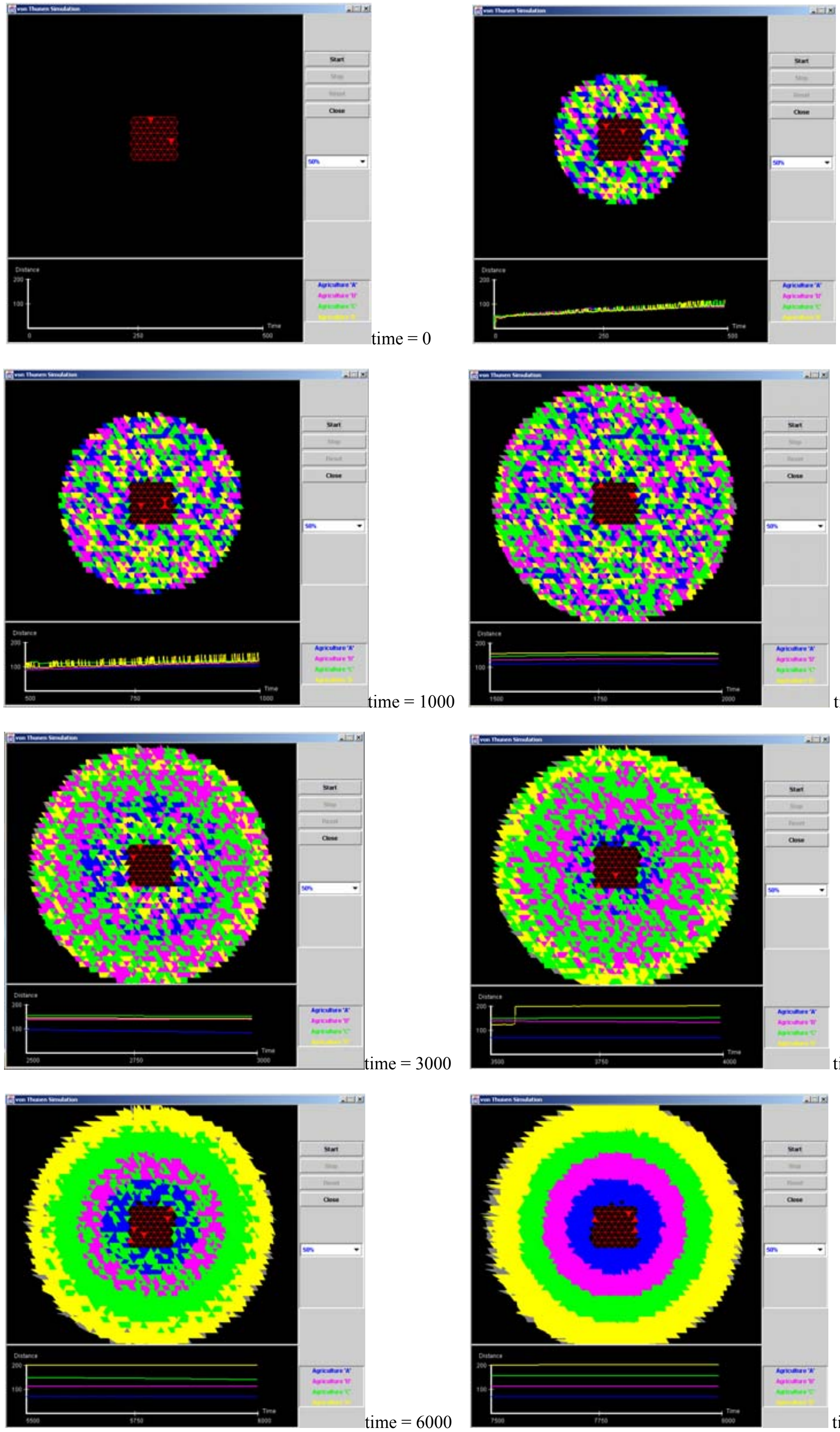
2- Choice behaviour

The main goal for the Farmer agent is to maximise their profit. At this stage the agent therefore determines whether it will remain practicing on current business, shift to another agricultural type, or give up its farm and become a city-dweller based on profitability. This behaviour can be expressed as:

```
if (farmer(i)Income – farmer(i)IncomLast) < minSatisfaction
analysisAgri(i)UrgentDemand = Yes          (extracted from Analysis agent's report)
        then Farmer(i) = Farmer(new)
                else if analysisAgri(i)UrgentDemand = No
                        then Farmer(i) = Farmer(dweller)
                        farmer(i)Shape = vacantLandShape
                                else if (farmer(i)Income – farmer(i)IncomLast) ≥ minSatisfaction
                                        then Farmer(i) = Farmer(i)
end if
```

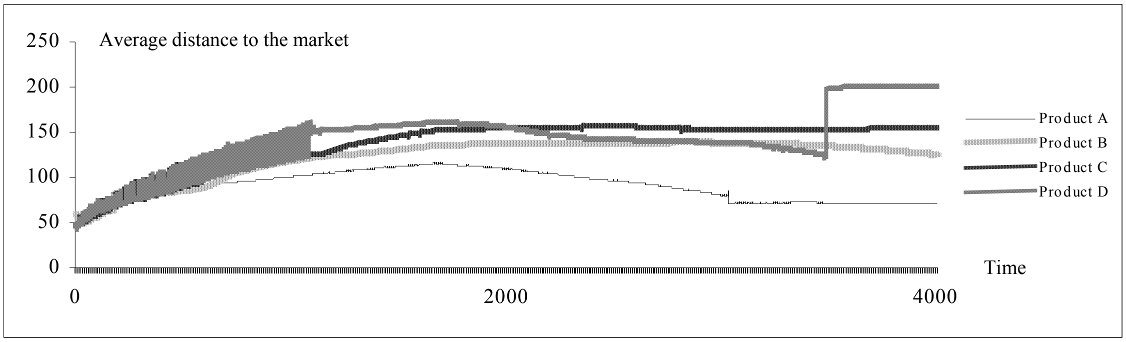
As the simulation starts, the model is initiated with no agricultural fields, and with all the Farmer agents occupying a city. With no agricultural fields and no agricultural production, the supply curves for all products are at 0, and opportunities for Farmer agents to produce all agricultural products are extremely high. This creates a land rush as Farmer agents settle the nearest surrounding areas to the market in a concentric ring, and set up production.

Figure 3.2 shows a typical simulation run for 8000 time steps. At 500 time steps relative distance of all products is equal from the market. After 2000 time steps, product A starts to allocate closer to the market (figure 3.3 A), but with no discernible pattern within the perimeter of the space. As the simulation progresses, there is a slight but noticeable increase in separation of the average distance of some products. Intensive agriculture (product A) moves noticeably closer to market, while forest (product B) and grain (product C) merge towards the same average distance. After 4000 time steps, a discernible aggregation of different agricultural types can be noticed into concentric rings, and by 6000 time steps the patterns are well established and remain indefinitely by 8000 time steps with incremental distance to the market regarding von Thunen's assumption (figure 3.3 B).

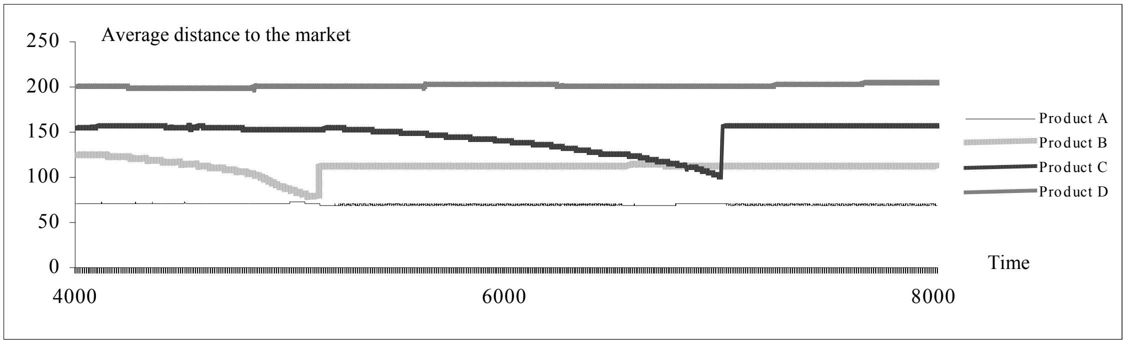


time = 0
time = 500
time = 1000
time = 2000
time = 3000
time = 4000
time = 6000
time = 8000

Figure 3.2. von Thunen's simulation result for first 8000 time steps.



A



B

Figure 3.3. Graphs show the distance to the market during the simulation run for each agricultural product

4.0 CONCLUSION

This paper has introduced a generic vector agent model as an alternative to cell-based models, testing it with the von Thunen model of agricultural land use. We began with a set of questions designed to explore the tendency in current spatial modelling (particularly CA), and focus our investigation on irregular vector agent modelling as a new approach in spatial simulation. We discussed the crucial issues of implementation, verification, and validation, noting the challenges that lie in empirical applications of this model.

It has been demonstrated that, in principle, irregular vector agent models are tools that can facilitate progress in the spatial simulation domain. We have seen, comparisons between the model strategy and the notion of CA elements such as spatial unit, neighbourhood, transition rules, states, and the nature of time in the model. These in turn have resulted in grounding the model hypotheses. A procedure for simulating irregular objects and manipulating their geometric boundary (through an irregular tessellation –like parcel) has been provided.

In terms of model calibration, the city is a complex system and understanding of urban evolution is highly essential to the future city development. The processes of such phenomena involve multiple-actors, multiple-behaviours and various policies, which results in its spatial and temporal complexity. Successful models should have stronger capacity of interpretation and an interactive environment to simulate hypothetical scenarios, which could be based on theoretical analysis of a specific city. As an initial step, the vector agent modelling environment has been applied to von Thunen's theory. Although it is not an urban model, it deals with land use change over space and time. Furthermore, it has been parameterised for cell-based agents by Sasaki and Box (2003), so von Thunen was chosen as available initial test.

It is noteworthy that the results observed here are quite similar to those observed by Sasaki and Box in that von Thunen's concentric ring pattern has been replicated. Thus, the model opens up a new era for getting the spatial simulation into higher degree of reality. Further research is essential especially for the model calibration with the real world data.

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